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EXPERIMENTS ON THE NEURAL BASIS OF MOVEMENT VISION

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A. INTRODUCTION

The capacity of animals to respond to the movement of visual stimuli constitutes an aspect of pattern vision of general significance in the study of visual function. Furthermore, theoretical speculation about the neural activity involved in movement vision has been the starting point in the formulation of certain broad systems of thought about the whole psychology of perception, although there is very little exact knowledge concerning the receptor and neural structures and their associated physiological functions which determine this capacity. An attempt has been made in the present experiment to measure certain quantitative characteristics of visual movement discrimination and to ascertain the functional value of different cortical regions and of the cortex as a whole in the mediation of particular types of movement perception. Specifically, the visually elicited head nystagmus of guinea pigs has been used to ascertain velocity thresholds for real movement before and after cortical ablations.

Movement discrimination in animals may be studied by observing either reflex adjustments or learned discriminative reactions to moving visual stimuli. Studies making use of learned responses have indicated in a limited way some phylogenetic differences in the ability of different vertebrates to respond to visual movement, although the data are not sufficiently extensive to formulate precise conclusions about the comparative physiology of movement vision. Comparison of velocity thresholds in the chicken (Stavsky and Pattie, **17**), rat (Hawley and Munn, **5**), and cat (Kennedy, **7**; Kennedy and Smith, **8**) seems to show some superiority of the cat in discriminating the movement of visual patterns. When tested under the same conditions,

the human individual is superior to the cat in discerning the presence of movement or in discriminating differences in velocity.

Utilization of the optokinetic reactions of animals as an indicator response has provided means for ascertaining velocity thresholds of movement discrimination in a number of animals. Data which have been reported for rabbit (ter Braak, 1), cat (Smith, Kappauf, and Bojar, 15), and man (15) indicate that the cat is superior to the rabbit but inferior to man in upper velocity thresholds. Whereas the human individual displays discrete nystagmus reactions at stimulus velocities up to 133 degrees per second, the cat does not respond at velocities above 110 degrees per second (15). The maximal velocity at which nystagmus movements are found in rabbits is approximately 70 degrees per second (1).

There have been a number of investigations of the effects of cortical lesions in various animals upon their ability to respond to moving stimuli. Experiments by van Herk and ten Cate (6), Lashley (10), Koudrin (9), Kennedy and Smith (8), and Kennedy (7) have provided data bearing on the residual capacity of animals to learn discriminatory reactions to visual movement after bilateral ablation of the occipital areas of the cortex. In all of these studies except those of Lashley, some positive evidence of postoperative learning or relearning of discriminative reactions to visual movement has been found. The experiments of Kennedy and Smith on cats indicate that partial bilateral lesions of the striate cortex distinctly raise the lower threshold of visual movement discrimination. The more extensive observations of Kennedy show that, with bilateral destruction of the visual cortex, the ability of the cat to respond to moving patterns is restricted for the most part to the discrimination of very simple patterns such as a moving bar or dot. The effects of removal of the occipital cortex upon optic nystagmus have been described in part. Smith, Kappauf, and Bojar (15) found no significant upper threshold loss in cats after bilateral destruction of the striate areas. Ter Braak (1) has reported that optic nystagmus in the rabbit, cat, dog, and monkey is not abolished by either occipital lesions or frontal lesions. He found that decorticate rabbits show a slight reduction in the upper velocity threshold of nystagmic responses. Visser and Rademaker (19) report that optic nystagmus is retained in decerebrate doves. These studies of optic nystagmus may be taken to indicate residual movement vision after abolition of the cortical projection areas of the retina. In certain other experiments, the occurrence of optic nystagmus has been used to show the retention of apparent-movement vision in cats lacking the occipital cortex (Smith and Kappauf, 14) and in decorticate guinea pigs (Smith, 13), and to measure visual acuity in cats lacking the occipital cortex (Smith, 11; Snith and Warkentin, 16).

B. Methods and Procedure

The method of eliciting optic nystagmus in the guinea pig has previously been described in some detail (13). The rotating drum which supplies the moving stimuli has also been used in experiments on cats and human subjects (15). Figure 1 provides an outline diagram of the experimental set-up.

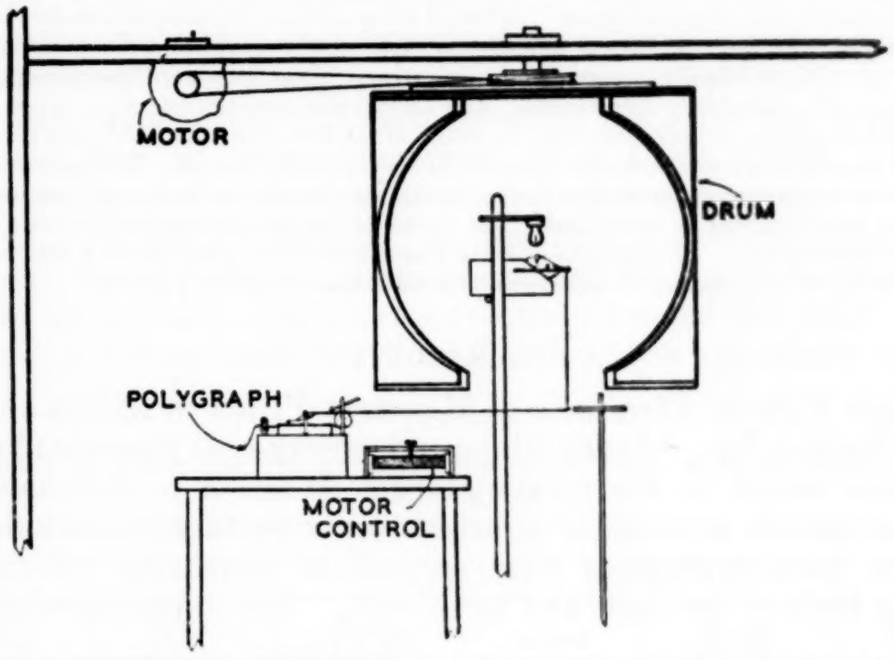

Fig. 1. The apparatus used in eliciting optic nystagmus in the guinea pig. In the diagram shown, only two of the stripes of the drum are represented.

The body of the drum is composed of fifty spherical ribs upon which are mounted strips of white glazed cardboard, cut so that the width of the strips is equal to the width of the interspaces in any horizontal plane. When light in the experimental room is limited to a single source within the drum, a pattern of black and white striations of high brightness contrast is secured. The cardboard strips constitute the white stripes while the black walls of the room, seen between successive strips, provide the intervening dark stripes. The drum may be rotated in either direction over a large range of velocities.

During observations on guinea pigs a frosted lamp located at the center of the drum provides the stimulus light. The animal, restrained in a box holder, is supported within the drum so that its head is several inches below the lamp and approximately in the axis of rotation of the drum. The head nystagmus of the subject is recorded mechanically on an ink-writing polygraph by means of a fine silk thread which is connected to the nose of the animal. Also mounted on the polygraph are a marker indicating time in seconds and another showing the onset and termination of the light stimulation.

At the beginning of an experimental session, the animal is prepared for observation as described above. After the room is darkened and the polygraph turned on, the drum is set in motion at a predetermined speed. A short pre-stimulation record is secured of the animal's movements, after which the light inside the drum is switched on for a period of approximately one minute. A short post-stimulation record is also secured. After a short rest period, a similar recording is made with the drum turning in the opposite direction. This process is repeated for different velocities of drum movement. Ordinarily the animal is first tested at a speed of five stripes per second,[1] and the velocity thereafter increased in steps of five stripes per second until a threshold is

[1] Hereafter, the term stripes per second will be used to designate the velocities of the drum at which records were secured. Since the drum contained fifty white stripes, a speed of five stripes per second would be equivalent to 0.1 revolutions of the drum per second, or 36 degrees per second.

reached, although smaller increments are sometimes used. Observations on normal and on operated animals are carried on in the same fashion.

C. Animals and Operations

The animals used as subjects included seven albino and twenty-nine pigmented adult guinea pigs. Fifteen of the twenty-nine pigmented guinea pigs were subjected to surgical operations involving lesions of the cerebral cortex. In five of these animals, the occipital areas of the cortex were removed. In three additional animals, removal of the occipital areas was followed by hemidecortication, and finally by complete decortication. Six animals were first hemidecorticated and subsequently completely decorticated. One animal was decorticated in one stage.

At the completion of the experiment, the brains of the five animals in which only the occipital areas had been removed were imbedded in celloidin and stained in thionin. All five brains showed degeneration of the external geniculate bodies, indicating that the cortical projection areas of the retina had been successfully extirpated. The brains of the ten decorticated animals were not examined histologically. Photographs of these brains have been presented in a previous publication dealing with the nature of apparent-movement vision in guinea pigs (13).

D. Results

Upper Velocity Thresholds of Movement Vision in Albino and Pigmented Guinea Pigs.—Seven albino and twenty-nine pigmented guinea pigs were tested in the rotating drum situation to determine the maximal speeds of rotation at which optic nystagmus occurs. Records of head nystagmus were secured at increasing velocities of rotation both to the right and to the left. The upper threshold was

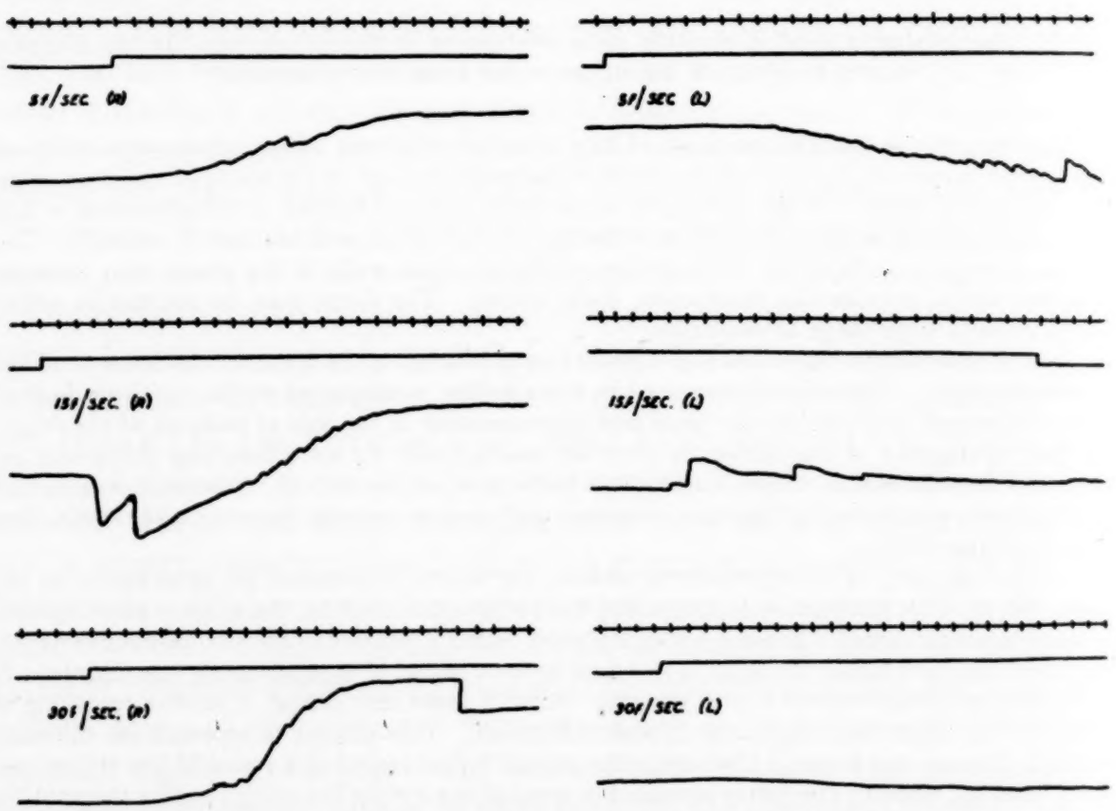

Fig. 2. The responses of a normal pigmented guinea pig at different velocities of rotation of the visual field. These records have been selected from a larger group of records taken on an animal which is more or less typical of the reaction of guinea pigs to moving striated patterns.

considered to be the highest velocity at which clear-cut pursuit movements could be elicited.

In Fig. 2 are shown typical records secured on a pigmented animal at three different speeds of rotation to the right and to the left. The records appearing at the left of the figure represent reactions to the right, and those at the right of the figure, reactions to the left. The drum velocities used in securing the three pairs of records were, from top to bottom in Figs. 2, 5, 15, and 30 stripes per second. It will be noted that with visual movement toward the right the animal displays clear-cut nystagmus reactions at all three speeds, but with movement toward the left no distinct pursuit movements occur at a speed of 30 stripes per second. In this particular animal, the thresholds were found to be 25 stripes per second for reactions toward the left and 30 stripes per second for reactions toward the right.

Table 1 summarizes the thresholds found in the albino and pig-

TABLE 1

COMPARISON OF THRESHOLD VELOCITIES OF MOVEMENT VISION IN ALBINO AND PIGMENTED GUINEA PIGS

Albino Animals			Pigmented Animals		
Subject	Stripes Per Sec	Degrees Per Sec	Subject	Stripes Per Sec	Degrees Per Sec
30	13	94	50	30	216
31	12.5	90	51	20	144
32	16	115	52	35	252
33	16	115	53	32.5	234
34	14	101	54	15	108
35	12	86	55	30	216
36	15	108	56	30	216
			57	30	216
			58	42.5	306
			59	40	288
			60	30	216
			61	25	180
			62	22.5	162
			63	27.5	198
			64	37.5	270
			65	37.5	270
			66	25	180
			67	37.5	270
			68	27.5	198
			104	20	144
			107	22.5	162
			108	32.5	234
			109	30	216
			110	32.5	234
			111	30	216
			112	25	180
			113	30	216
			115	27.5	198
			118	27.5	198
Mean	14	101	Mean	29	212

mented animals. The numbers appearing in the body of the table represent the mean of the two values found for movement to the right and to the left. The threshold values are given in terms of stripe frequency as well as degrees of angular movement per second. The pigmented animals were tested at velocities which increased in steps of five stripes (36 degrees) per second, but smaller increments were employed in testing the albino guinea pigs. Examination of the data given in the table will show that the albino animals displayed threshold values ranging from 12 to 16 stripes per second. In comparison, pigmented animals responded with definite pursuit movements to stimulus velocities as high as 45 stripes per second. Threshold values for the pigmented animals vary widely, however, ranging from 15 to 45 stripes per second. The mean threshold velocity for albino animals is 14 stripes per second, while that for pigmented animals is 29 stripes per second.

2. *Upper Velocity Thresholds of Movement Vision after Removal of the Occipital Areas of the Cortex.*—Subsequent to testing in the normal condition, eight pigmented guinea pigs were subjected to an operation involving the removal of the posterior half of the cerebral cortex. The success of the operation in destroying the visual projection areas was confirmed on five animals (Subjects 57, 58, 60, 62, and 63) by histological examination of the external geniculate bodies. The remaining animals of the group (Subjects 112, 113, and 115) were used for additional operative procedures, culminating in complete decortication.

TABLE 2

TERMINAL THRESHOLDS OF MOVEMENT VISION BEFORE AND AFTER REMOVAL OF THE OCCIPITAL AREAS OF THE CORTEX

Subject	Preoperative		Postoperative	
	Right	Left	Right	Left
57	30	30	35	25
58	45	40	45	45
60	35	25	25	25
62	20	25	25	20
63	25	30	30	20
112	25	25	25	30
113	30	30	25	35
115	25	30	30	30
Mean	29	29	30	29

Data secured on these eight animals both preoperatively and postoperatively are summarized in Table 2. In this table, upper threshold values for visual pursuit movements are given for reactions both to the right and to the left. It is to be noted that there is no

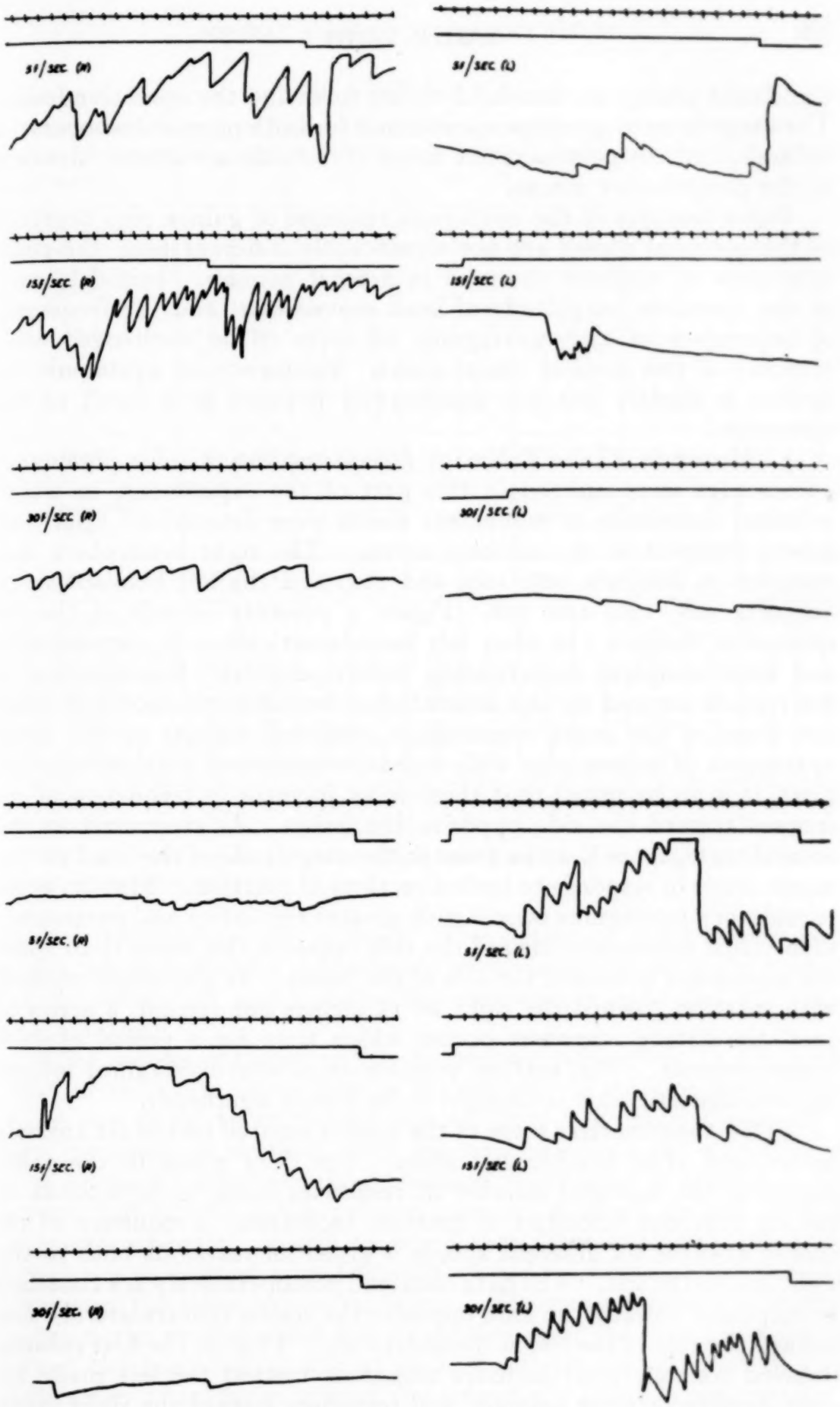

FIG. 3. Optic nystagmus in a pigmented guinea pig (Animal 110) after left hemidecortication (Upper records) and complete bilateral decortication (Lower records) at three different velocities of rotation.

significant change in threshold values following the operative lesion. The range is 20 to 45 stripes per second for both normal and operated animals, and the postoperative mean thresholds are almost identical to the preoperative means.

Other features of the nystagmic response of guinea pigs deprived of the occipital cortex are not significantly different from the characteristics of response observed in normal animals. Initial latency of the reactions, magnitude of head movements, and the frequency of occurrence of after-nystagmus all seem to be unchanged after removal of the cortical visual areas. Frequency of nystagmic reactions is slightly but not significantly lowered as a result of the operation.

3. *Movement Vision Following Hemidecortication.*—Six pigmented guinea pigs were utilized in this part of the experiment, in which terminal thresholds of movement vision were determined after unilateral removal of the cerebral cortex. The right hemisphere was removed in Subjects 107, 109, and 111, and the left hemisphere in Subjects 108, 110, and 118. Figure 3 presents records of the responses of Subject 110 after left hemidecortication (upper records) and after complete decortication (lower records). Examination of the records secured on this animal after hemidecortication will bring out some of the most consistently observed aspects of the optic nystagmus of guinea pigs with extensive unilateral cortical injuries. First, it is to be noted that there is an increase in frequency of responses toward the side opposite the lesion. As compared to the normal state, there is an increase in the magnitude of the head movements made in response to both directions of rotation. Finally, post-stimulatory nystagmus occurs with greater regularity and persistence with visual movement toward the side opposite the lesion than when the movement is toward the side of the lesion. In the record secured with rotation toward the right at 15 stripes per second, a series of post-stimulatory responses occurs which lasts for a period of over fifteen seconds. This marked persistence of after-nystagmus following hemidecortication is thought to be highly significant.

Table 3 summarizes some of the results secured on the six animals before and after hemidecortication. The data given in the table represent the maximal number of responses made in 30 seconds at the six different velocities of rotation indicated. Frequency of response at these six different speeds is given for reactions both to the right and to the left. The data obtained postoperatively are classified as responses toward the side opposite the lesion (contralateral) and toward the side of the lesion (homolateral). That is, the first column (labeled contralateral) includes responses toward the left made by right hemidecorticate animals, and responses toward the right made

TABLE 3

MAXIMUM RESPONSES IN THIRTY SECONDS BEFORE AND AFTER HEMIDECORTICATION

Stripes Per Sec	5		10		15		20		25		30	
Dir. of Movement	R	L	R	L	R	L	R	L	R	L	R	L
Subjects Preop.												
107	18	21	4	11	6	2	3	4	6	2	0	0
109	14	16	36	12	7	9	5	2	3	2	1	1
111	14	23	12	12	12	13	11	12	1	3	2	5
108	9	7	15	3	12	4	9	9	10	1	11	0
110	16	21	23	22	7	13	7	8	3	5	4	4
118	22	21	40	19	36	12	25	12	18	13	1	4
Mean	16	18	22	13	13	9	10	8	7	4	3	2
Combined Mean	17		18		11		9		6		2	
Dir. of Movement	C*	H*	C	H	C	H	C	H	C	H	C	H
Subjects Postop.												
107(R)	23	21	7	13	11	10	10	9	11	7	9	2
109(R)	18	9	16	4	44	4	30	4	11	3	6	3
111(R)	27	16	41	9	8	13	7	9	7	7	4	8
108(L)	20	17	32	2	29	5	23	6	28	9	16	4
110(L)	23	22	37	11	14	3	9	2	8	4	7	1
118(L)	20	21	10	19	13	12	12	13	8	4	4	1
Mean	22	18	24	10	20	8	15	7	12	6	8	3

* C and H refer respectively to Contralateral and Homolateral direction of movement, with respect to the operative lesion.

by left hemidecorticate animals. The nature of the lesion in each subject is described by the letters in parentheses following the number of the subject, R and L indicating respectively right and left hemidecortication.

The results obtained on the normal animals, given in the upper part of the table, show that as the velocity of rotation is increased from five to thirty stripes per second there is a gradual decrease in the frequency of reaction, until the responses drop out altogether as the threshold for responding to visual movement is reached. The lower half of the table presents results obtained on the hemidecorticate animals. It will be noted that there is a fairly consistent tendency to respond more frequently when the direction of movement is toward the side opposite the lesion. The mean number of responses toward the contralateral side is greater than the mean number toward the homolateral side at each of the six velocities used. The frequency of response toward the side of the lesion is comparable to

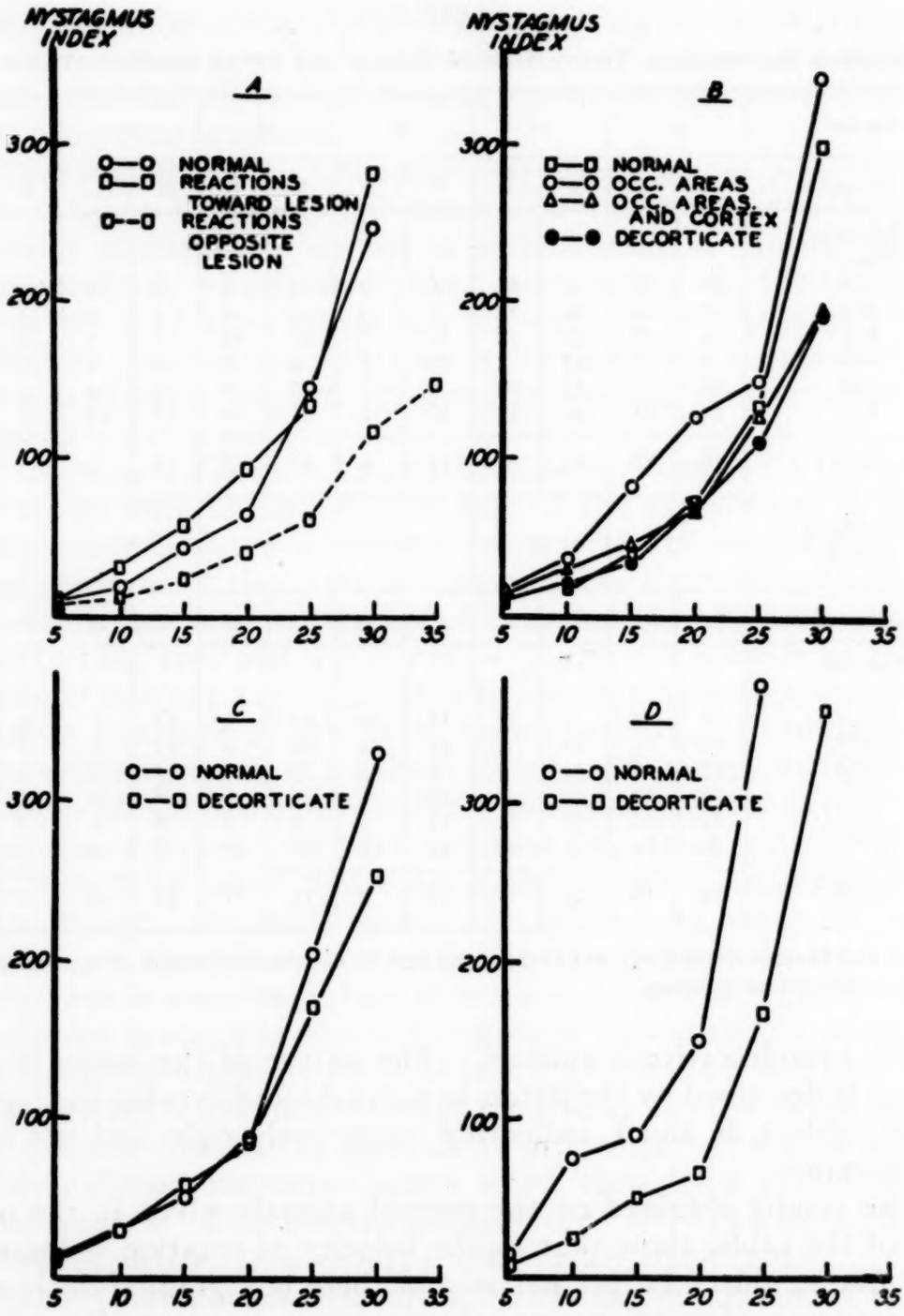

FIG. 4. The nystagmus index plotted as a function of velocity for normal animals and for these same animals after different operative lesions on the cerebral cortex. (*A*) The nystagmus index for a group of normal animals and for these animals ipsilateral and contralateral to the lesion following hemidecortication. (*B*) The nystagmus index at different velocities for normal animals, after removal of the occipital cortex, after hemidecortication combined with removal of the occipital cortex of the other hemisphere, and after complete bilateral decortication. (*C*) The nystagmus index at different velocities before and after complete bilateral decortication, carried out in two stages. (*D*) The nystagmus index for one animal before and after bilateral decortication, carried out in one stage.

the mean frequency for the normal animals at the corresponding velocity.

In Fig. 4 the data have been plotted in terms of a 'nystagmus index,' which may be taken to indicate the efficiency with which the animal follows the moving stripes. This index, which represents the number of stripes passing per response, is calculated from the average duration of one response during the 30-second period of maximal response frequency. The average number of stripes passing per response is then plotted as a function of the velocity. The lower the index, the more efficient is the nystagmus in responding to the moving stripes; *e.g.*, an index value of 1 would indicate that the animal responded to each stripe individually.

We shall consider for the moment Part *A* of Fig. 4, which presents data for normal animals and for the same animals after hemidecortication. For these graphs, as in Table 3, the data from the hemidecorticate animals have been classified as responses toward the side of the lesion and responses toward the side opposite the lesion. The graphs show clearly the effect of hemidecortication which has been mentioned above, that responses toward the side opposite the lesion are increased in frequency, especially at higher velocities. The graphs show also that, in hemidecorticate animals, responses made toward the side opposite the lesion are more effective in adjusting to the velocity of the moving stripes. The nystagmus index for reactions toward the side of the lesion in the hemidecorticate animals corresponds closely at all velocities of rotation to the index of normal animals. Apparently the operation does not materially change the reactions toward the ipsilateral side but distinctly modifies the reactions toward the contralateral side.

Three animals (Subjects 112, 113, and 115) were hemidecorticated following removal of both occipital areas. The second operation involved removal of the remaining tissue of the left hemisphere in Subject 112, and of the right hemisphere in Subjects 113 and 115. These animals were completely decorticated in a third operation. The data secured on these three animals are plotted as a nystagmus index in Part *B* of Fig. 3. The curves given represent the combined averages for all three animals in both directions of rotation for the normal state, after removal of the occipital areas, after hemidecortication combined with removal of the other occipital area, and after complete bilateral decortication. It is clear that these successive operations do not limit the effectiveness of the guinea pig's nystagmic response to moving stimuli. If anything, there is a slight increase in effectiveness at the higher velocities of rotation following hemidecortication and decortication.

4. *Movement Vision Following Bilateral Decortication.*—The effect of bilateral decortication upon visual head nystagmus in guinea pigs was observed in ten animals. Nine of these animals had been used in previous parts of the experiment, after operations involving partial removal of the cortex. In one case only (Subject 104) was complete decortication carried out in one stage after the animal had been tested preoperatively.

Figure 3 illustrates the nature of the records secured on one of the guinea pigs (Subject 110) after left hemidecortication (upper records) and after decortication (lower records). It has been noted above that after left hemidecortication, responses toward the right are increased in frequency and magnitude. Consideration of the lower records shows that removal of the remaining cerebral cortex (right hemisphere) affects similarly the responses made toward the left. But now the responses toward the right are reduced markedly in magnitude and slightly in frequency. These changes were observed in all of the decorticate animals. After-nystagmus occurs in the completely decorticate guinea pig but, in general, is not as marked as in the hemidecorticate animal.

The results secured on the completely decorticate animals are summarized in Part *C* of Fig. 4, in which the nystagmus index of normal and decorticate animals is plotted as a function of the velocity of rotation. These graphs show what has already been indicated, that the decorticate guinea pig follows moving stripes at least as well as, and perhaps somewhat better than, the normal animal. It is possible that the removal of the cerebral cortex in the guinea pig releases the nystagmic reactions from cortical control and thus brings about a greater frequency of response in the operated than in the normal animal. However, the difference which exists between normal and decorticate animals is not as marked as that which exists between pigmented and albino guinea pigs.

The number of stages involved in the operative procedure of decortication apparently does not affect the nature of the postoperative nystagmus. Part *D* of Fig. 4 gives the nystagmus index pre- and postoperatively for Subject 104, in which the cortex was removed in one stage. It will be seen that even this radical operation did not alter the animal's ability to respond to the moving stripes.

The data just presented on decorticate guinea pigs were obtained from three to five days following the final operation. When these animals were tested in the rotating drum three to six hours after recovery from the anaesthesia, deficiencies in nystagmus and movement vision were very apparent. Most of the animals showed no responses at all during this time, although a few gave markedly deficient reactions.

5. *Terminal Thresholds of Movement Vision in Hemidecorticate and Decorticate Guinea Pigs.*—It has been shown above that the removal of the occipital areas of the cortex in guinea pigs does not reduce their upper velocity thresholds of movement vision. Table 4 summarizes data showing that hemidecortication and decortication likewise do not lower the terminal thresholds. Ten animals are included in the table, nine of which were hemidecorticated and then decorticated, one of which was decorticated in one operation. The letters R and L following the number of the first nine subjects indicate right and left hemidecortication respectively. Subjects 112, 113, and 115 are included in this summary, although their occipital areas were removed prior to hemidecortication. As usual, the terminal thresholds are given in stripes per second.

TABLE 4

TERMINAL THRESHOLDS OF MOVEMENT VISION IN NORMAL, HEMIDECORTICATE AND DECORTICATE ANIMALS

Condition	Normal		Hemidecorticate		Decorticate	
Direction	R	L	R	L	R	L
Subjects						
107(R)	25	20	30	40	25	20
108(L)	30	35	45	40	30	40
109(R)	30	30	30	40	25	25
110(L)	35	30	30	30	25	30
111(R)	30	30	35	35	25	25
112(L)	25	25	40	40	45	45
113(R)	30	30	30	35	25	30
115(R)	25	30	30	30	35	35
118(L)	25	30	30	25	40	35
104*	30	30			35	30
Mean	28	29	33	35	31	32

* Both cortices removed in one operation.

The data in the table show that the removal of one cortex or of both cortices produces no marked change in the maximal velocity at which optic head nystagmus occurs. In fact, a slight but statistically insignificant increase in the terminal thresholds appears postoperatively.

E. DISCUSSION

When the visual field of the guinea pig is rotated at a moderate velocity, a series of head movements occur which are similar to the familiar eye nystagmus produced by optic or vestibular stimulation. As the speed of rotation is increased, the frequency of the responses is

gradually reduced until they finally disappear altogether. This variation in the frequency of the nystagmic movements as a function of velocity has permitted the calculation of a nystagmus index, which is equivalent to the number of stripes passing a point in the visual field during the mean duration of one response. The nystagmus index has been employed in describing the nature of movement vision in pigmented guinea pigs before and after cortical operations.

The results of the experiment show that the pigmented guinea pig is superior to the albino animal in ability to respond to moving visual patterns. Whereas the mean upper velcoity threshold of response found for the albino guinea pig is 101 degrees per second, the mean threshold of the pigmented animal is 212 degrees per second. The terminal velocity threshold found here for pigmented guinea pigs corresponds closely to the maximum speeds at which eye nystagmus is observed in cats and in the human individual when tested under similar conditions (Smith, Kappauf, and Bojar, **15**).

In these experiments removal of the occipital areas of the cortex, hemidecortication, hemidecortication combined with destruction of the occipital half of the other cortex, and complete bilateral decortication produced no apparent deficiencies in movement vision as indicated by the occurrence of optic nystagmus. The upper velocity thresholds were as high postoperatively as preoperatively. The nystagmus index was substantially unchanged following removal of the occipital areas. In the hemidecorticate animals, the index is lowered for reactions toward the side opposite the lesion, especially at the higher velocities, indicating an increase in the efficiency with which the animal responds to the moving stripes. Finally, the phenomenon of after-nystagmus occurred somewhat more frequently and persistently in the operated animals than in normal animals. This is especially true of hemidecorticate animals when the visual field is rotated toward the side opposite the lesion. The conclusion must be drawn that partial or complete cortical lesions do not limit the capacity of the guinea pig to give nystagmic reactions to moving visual patterns.

The present results fail to confirm observations of ter Braak (**1**) that deficiencies in optic nystagmus occur in rodents as a result of complete decortication. Rather, the results agree with previous findings on the cat, which showed no marked reduction in terminal thresholds of optic nystagmus after destruction of the striate areas of the cortex (Smith, Kappauf, and Bojar, **15**). Observations by Broers and de Kleijn (**2**) on dogs and of Strauss (**18**), Fox (**3**), and Fox and Holmes (**4**) on the human individual, which indicated that unilateral lesions of the optic centers of the cortex produce inequalities

of optic nystagmus with different directions of movement, have been interpreted as showing deficiencies in nystagmus when the stimulus pattern moves toward the side of the lesion. However, no preoperative observations were made in these studies. The present results also show directional inequalities in frequency following unilateral lesions, but comparison of postoperative with preoperative results shows that the inequality must be interpreted as an increase in frequency of responses toward the side opposite the lesion rather than a decrease toward the side of the lesion. The results described by Broers and de Kleijn, by Strauss, Fox, and Fox and Holmes perhaps may be similarly interpreted.

One important conclusion which may be drawn from the present work is that the cortex does not contain direct pathways which mediate the visual pursuit reactions produced by movement of striations across the visual field. Observations described elsewhere have shown that the collicular centers do mediate the nystagmic responses (Smith, 12). The cortex appears to level a type of regulatory control over the strength and frequency of the responses, which in the normal animal appears as a restraining or inhibitory function, for the responses show greater strength and frequency following extensive lesions of the cortex. Since there is little change in the nature of the responses following removal of the occipital areas, it is possible that the frontal areas of the cortex exercise a restraining influence on nystagmic responses made toward the contralateral side. The results described on hemidecorticate animals are agreeable with this interpretation. Such an inhibitory function of the cortex has been suggested previously in connection with stimulatory inactivation of the nystagmic responses before and after cortical ablations.

It remains to show to what extent the present results bear upon the more general problems of the perception of movement. In an extensive and carefully controlled study of learned movement discrimination in cats, Kennedy (7) has shown that upper velocity thresholds are distinctly lowered after removal of the visual centers of the cortex. There are at least two possible explanations of the conflict between Kennedy's results and results of the visual nystagmus studies. First, it is possible that the threshold losses observed in the discrimination studies represent deficits in learning capacity following cortical lesions which can be eliminated only by more extensive postoperative training than was given the subjects. Second, the author has shown previously that some deficiencies in movement vision following cortical lesions in the cat are due to a loss of the capacity of the animal to respond to single, isloated objects in the field of vision (Smith and Warkentin, 16). Since animals which lack

a central retinal area of acute vision, such as the guinea pig, do not respond visually to the movement of single objects, it may be suggested that destruction of the cortical visual areas in cats interferes with the central connections of the *Area centralis*. In other words, cats lacking the visual areas of the cortex respond to moving stimuli in much the same way as do animals lacking a central area of acute vision. If this be true, the deficiencies in movement vision in cats lacking the visual cortex which have been described by Kennedy may be redefined as the loss of the ability to resolve single isolated patterns in the field of vision effectively.

Available data indicate that movement vision, as related to a series of moving stimuli, suffers no deficiencies following removal of the cortex. We may conclude, then, that the subcortical centers of the optic system resolve and maintain the temporal and spatial differences in the pattern of retinal activity which constitutes the initial neural basis of movement vision, and that they perform this function equally well whether the cortex is present or absent. This conclusion precludes acceptance of any theory of movement vision which postulates processes of interaction between spots of activity in the cortex as underlying neural mechanisms. Rather, the various types of movement vision have the complexity and multiple neural determination now understood to be associated with the fundamental reflex processes of the nervous system.

F. Summary

1. Threshold velocities of movement vision and the frequency of optokinetic head nystagmus as a function of the velocity of movement of a striated visual pattern have been determined in guinea pigs by means of the rotating drum method and appropriate recording apparatus.

2. The maximal velocity threshold of movement vision in the pigmented guinea pig is almost double that of the albino animal. The threshold of albino animals is somewhat greater than that which has previously been determined for the rabbit (ter Braak, 1), but the pigmented guinea pig shows a threshold comparable to those found in the cat and human individual, when tested under similar conditions (15).

3. Cortical operations involving the removal of the occipital areas of the brain, hemidecortication, hemidecortication combined with removal of the occipital area of the other cortex, and complete bilateral decortication produce no change in the upper velocity thresholds at which movement fusion seems to occur.

4. The removal of one hemisphere results in an increase in the frequency and magnitude of nystagmic responses when the stimulus pattern moves toward the side opposite the lesion. Under the same conditions, the nystagmus index, a measure of the number of stripes passing per response, is lower. These facts suggest that under normal conditions the cortex exercises a restraining influence on optic nystagmus.

5. The results show conclusively that movement vision for striated patterns may be maintained with no apparent deficiencies by subcortical centers in the absence of the cortex in the guinea pig.

6. It is concluded that movement vision in its various aspects is under multiple control by cortical and subcortical centers. The principle function of the cortical centers is to mediate movement vision for isolated patterns in the visual field, while the subcortical centers may mediate responses based on the movement of complex striated patterns. Since the guinea pig does not normally respond to the movement of isolated objects, its capacity for movement vision remains practically unchanged following removal of the cortex.

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A STUDY OF THE SIMILARITY OF WORK DECREMENT CURVES*

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Introduction

Since the time of Mosso the problem of type constancy among individual ergograms has attracted the attention of a number of investigators. Marks (9) summarizes the efforts of previous workers to decide whether or not the work curve is characteristic to the person who produces it, and concludes on the basis of his own experiment that no constancy can be found in the shape of the curve, although in respect of individual features of the curve some constancy exists.

Previous experiments on this problem may be divided among those which treated the question by the method of qualitative analysis and those which, like Marks' experiment, subjected the ergograms and their covariations to quantitative treatment. Those who used the qualitative method include Mosso (10) himself, Maity and Sinha (8), Yochelson (12 & 14) and Antipoff and Assunçao (1). Quantitative methods were used by Crawley (2) who observed the statistical dependence of the amount of work done in one sitting upon the same quantity as it appeared in a second sitting, Maity and Sinha as well as Antipoff and Assunçao both of whom showed that in specific aspects of the work curve less variability was observed within the subject's records than within the total sample of records under study, and Marks, whose work is much more extensive than that of anyone yet mentioned, and who used the method of correlation as well as a curve fitting technique to handle the problem.

Among the previous experiments considerable difference exists in the conditions of the experiment. Only Marks used a sample sufficiently large to accommodate the requirements of statistical reliability. Mosso used two subjects, Crawley used four subjects, Antipoff and Assunçao used twenty-one, Maity and Sinha ten, and Marks used one hundred and sixty-four, of whom fifty were selected for intensive study of certain aspects of the problem.

No great uniformity has obtained in the members of the body used in the experiment. Mosso, Maity and Sinha, and Antipoff and

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Assunçao used finger ergograms. Marks used arm ergograms. Yochelson used finger, hand, arm, leg, and trunk ergograms and Crawley used arm and leg ergograms. In some instances as in Yochelson's work the ergograms compared were taken from different members of the body. In other instances, as in the case of Marks, the ergograms compared were taken from the same member of the body. It might be pointed out further that observations reported on this problem have frequently been made during the course of experiments on other problems pertaining to the ergogram. Yochelson was interested in the effect of rest-pauses upon the ergogram; Crawley was interested in the rate of recovery from fatigue.

An important characteristic of research on this problem is the fact that in many instances the observations made have been confined to only a few aspects of the ergogram. Crawley studied the total amount of work done, Maity and Sinha studied the coefficient of fatigue, *i.e.* the decrease in the ratio of the initial to later efficiencies as measured by the mean work done in each series of ten excursions on the record. Antipoff and Assunçao studied the total amount of work, the duration of the period in which the subject worked, and the coefficient of fatigue. Marks studied the average number of pulls per unit of time, the rate of change of this number, the average length of the middle stroke of each interval and rate of change of this variable, the irregularity of the strokes and finally a measure of the failure of the subject to relax after each pull. In addition, Marks fitted his curves to Ioteyko's (**6**) third degree parabola in order to ascertain the value of certain constants of that function.

The present experiment had as its purpose the further investigation of the general problem studied by Marks. However, certain important changes in technique have been introduced. Marks studied the similarity between ergograms taken from the same member of the body. The present investigation studied similarity in ergograms taken from different members of the body. Like Marks the present investigator used a large number of subjects. Unlike Marks' experiment the subjects in this case were required to work in unison with a metronome until the onset of exhaustion. Marks used a spring ergograph and male subjects, we used a weight ergograph and female subjects. An important difference between this research and Marks' research lay in the treatment of the ergograms. Marks studied both specific characteristics of the ergogram, *i.e.* the average number of pulls per unit of time, etc. and the general configuration of the curve by the method of Ioteyko's third degree parabola.

In the present investigation a number of variables were selected, which taken collectively serve to individualize the curve. Included in the variables were: the amount of work done, the temporal interval

during which the subject labored, the percentage of work done during each quarter of the working period, the percentage of work done during the first half of the working period, the percentage of work done which in the case of each pull exceeded one half the mean of the five highest excursions on the record, the mean of the distribution of the differences (sign of the difference ignored) between successive excursions on the record, the Standard Deviation of the distribution of successive differences. No use was made of the curve-fitting technique.

The use of these measures and the decision not to rely upon the fitting of curves was made on two grounds. In the first place, the selection of a generalized work curve is a very hazardous undertaking. While Ioteyko has advanced reasons for the use of a third degree parabola, it may be pointed out that the choice of degree is a matter of hazard in view of the enormous variety of curves already noted in the literature. The use of empirical equations is, of course, always accompanied by hazard but the selection of a curve type in the case of the work curve is exceptionally risky. This conclusion is supported by the very low reliabilities on two of the four coefficients calculated on the curves reported by Marks. In the second place, Marks was obliged to conclude that the application of this technique yielded no evidence of consistency from ergogram to ergogram of the same subject. We are inclined to the opinion that the absence of constancy might well be a function of the inadequacy of the method used rather than of the character of the data.

The selection of the measures enumerated above was made principally by considering differences which might be expected in the proportion of work done during certain fractional parts of the working period in the case of records representative of the typical curves enumerated by Yochelson, Antipoff and Assunçao, and others. For example, that type of ergogram which is observed when the subject works at an undiminished level to collapse in the final seconds of the working period yields a high percentage value when the percentage of work done on all strokes which exceeds half the value of the longest stroke is calculated. The same record gives, of course, close to 25 percent on each of the quarters of the ergogram. By similar reasoning each ergogram can be shown to yield a characteristic pattern of percentages. No formal reason exists, of course, which prevents the indefinite fractionation of the working period. The present experiment might well have studied certain of the eighths of the period but for reasons of expediency the study was confined to the quarters.

Beyond the ground covered by Marks in his experiment is the possibility suggested by his results, namely that the degree of similarity between records taken from the same person may be regarded as

finding a position on a continuum ranging from absolute similarity at one extreme to absolute dissimilarity at the other. The present investigation attacks not only the question of similarity specific to a single pair of records, but also the question of general similarity among sets of four records, each set being taken from different members of a single subject.

Apparatus and Method of Procedure

The apparatus used was an ergograph built for the purpose by John R. Roberts, of the Psychological Laboratory, University of Pennsylvania, and described in a recent issue of this Journal (3).

One hundred women, graduate and undergraduate students at the University of Pennsylvania, served as subjects in the experiment. From each subject were taken four records—one from the right arm, one from the left arm, one from the right middle finger, and one from the left middle finger. Previous to the appearance of the first subject a table was prepared showing the twenty-four permutations of four items. The order in which any subject yielded the four records was determined by this table so that no one order would be a factor in the final outcome of the experiment. All possible orders were represented at least four times among the one hundred subjects and no order was represented more than five times.

The experiment was conducted daily from January until May 1938 between 9 A.M. and 12 o'clock noon. No subject was taken before 9:00 A.M. nor in the afternoon. Prior to the execution of the task required of the subject, a questionnaire was filled in covering the following items of information: Name, date of birth, age, height, weight, major subject, University status (Freshman, Sophomore, Junior, Senior, Graduate), the amount of breakfast the subject had had on the day of the experiment, the number of classes she had had before the hour of the experiment, and whether or not she felt well. No subject was used unless she reported that she was in good health.

Throughout the entire experiment the following experimental conditions were strictly observed: (1) The metronome was timed to beat at the rate of 100 beats per minute. (2) Each subject was given five trial pulls before an experimental record was taken, and one minute rest was permitted after the trial pulls were completed. These trial pulls were clearly recorded on each ergogram as 'trial pulls.' (3) The weight was the same for all subjects—approximately eight kilograms for the arms and 2.5 kilograms for the middle fingers, including the weight of the frame supporting the discs.[1] (4) A rest period of five minutes was given each subject between working periods. During the rest period the subject was unstrapped from the ergograph and permitted to rest free from annoyance. (5) The instructions used in the experiment are reproduced below. They were read to the subject before each ergographic record was taken. In cases of the finger ergograms the word 'finger' was substituted for the word 'arm' whenever the latter appeared in the instructions.

> "There is a heavy weight attached to the other end of this chain. You are requested to lift the weight as far as you can on the first stroke of the metronome and to release it on the stroke immediately following. Do this with the rhythm of the metronome—like this: one, two, one, two (a demonstration by the experimenter followed)—until your arm is so tired that you cannot lift the weight on the strokes of the metronome.
>
> "Please, be sure that you lift the weight as far as you can EVERY TIME and that you do this in rhythm with the metronome. First, I shall give you five trial pulls; then you will have one minute rest, following which, you will begin work and continue lifting the weight as instructed. Is everything clear to you? Are you ready? Go ahead."

In addition, measures were taken to maintain the temperature of the room between 65° F. and 73° F., to provide a constant supply of fresh air, and to make the subjects as comfortable as possible in the apparatus. The subjects worked without either coat or overcoat.

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[1] Due to the constancy of the weights used in the experiment, it was unnecessary to express the amount of work done by each subject in kilogram-meters. For the purpose of this research, therefore, the height to which the weight was lifted each time determines directly the output of work by the subject.

On the basis of the information found in the questionnaire and in the ergograms, the following values were computed for each subject:

1. Subject's height.
2. Subject's weight.
3. Height-Weight ratio.
4. Age in months.
5. Total number of pulls in each of the four ergograms. This number is, of course, a direct measure of the length of time during which the subject worked before the onset of exhaustion.
6. Total amount of work recorded in each of the four ergograms.
7. The percentage of work done in first quarter of working period in each ergogram.
8. The percentage of work done in second quarter of working period in each ergogram.
9. The percentage of work done in third quarter of working period in each ergogram.
10. The percentage of work done in fourth quarter of working period in each ergogram.
11. The percentage of work done in first half of working period in each ergogram.
12. The percentage of work done in upper half of each ergogram.
13. The mean of the distribution of successive variations on each ergogram. In this case the work done on each excursion of the stylus was compared with the work done on the preceding excursion. These differences were summed without regard to sign and divided by the number of possible differences, *i.e.*, one less than the number of excursions.
14. The Standard Deviation of the distribution of successive variations on each ergogram. This value was calculated by evaluating the Standard Deviation of the distribution of the differences described under (13). If the tendency to vary was uniformly exhibited throughout the working period, it tended to be a low number. If, on the other hand, the tendency to vary from pull to pull was not exhibited uniformly, this number tended to increase.

Results

Table I gives the distribution of ages of all subjects expressed in months. Examination of this table indicates that eighty-two of the

TABLE I

Showing the Distribution of Ages of One Hundred Subjects Expressed in Months

Ages in Months	Frequency
500–524	1
475–499	0
450–474	0
425–449	0
400–424	1
375–399	1
350–374	8
325–349	1
300–324	3
275–299	3
250–274	27
225–249	33
200–224	22
	$N = 100$

group of 100 subjects were less than 275 months old and that none of them were less than 200 months of age. After the data of the experiment had been collected and before they were treated, the work of

those 18 subjects who were older than 275 months was compared with the work of the eighty-two subjects less than 275 months in age.

Examination of these comparisons disclosed that the Critical Ratios were in general considerably less than 3.00, the highest being 3.00 in the case of the mean of the distribution of the variations on the right finger, 38 out of 42 were less than 2.00, while 19 out of 42 were less than 1.00.

In view of the general lack of difference between the data from the two groups, it was decided that their amalgamation into a single group of one hundred subjects would introduce no undue heterogeneity into the data which could be used to account for the magnitude of correlations later to be obtained. Accordingly, the data from the two groups were combined into a single distribution and later treatment was based exclusively on the entire sample taken.

TABLE II

SHOWING THE INTERCORRELATION ON ALL VARIABLES STUDIED BETWEEN ALL POSSIBLE PAIRS OF THE FOUR MEMBERS USED IN THE EXPERIMENT

1	2	3	4	5	6	7
Variables	RA–LA	RF–LF	RA–RF	RA–LF	LA–RF	LA–LF
1. No. of Pulls	.77±.06	.71±.07	.45±.09	.52±.08	.51±.09	.54±.08
2. Total of Work	.72±.07	.70±.07	.40±.09	.35±.09	.33±.09	.37±.09
3. % of W. Q 1	.63±.08	.62±.08	.51±.09	.58±.08	.64±.08	.55±.08
4. % of W. Q 2	.48±.09	.44±.09	.18±.10	.30±.10	.37±.09	.30±.10
5. % of W. Q 3	.43±.09	.52±.08	.39±.09	.46±.09	.47±.09	.42±.09
6. % of W. Q 4	.73±.07	.64±.08	.63±.08	.55±.08	.61±.08	.49±.09
7. % of W. 1st Half	.68±.07	.64±.08	.56±.08	.63±.08	.77±.06	.59±.08
8. % of W. Upper Half	.50±.09	.45±.09	.45±.09	.49±.09	.51±.09	.59±.08
9. Mean Succ. Var.	.65±.08	.38±.09	.10±.10	.33±.09	.26±.10	.31±.10
10. S.D. of variat.	.42±.09	.29±.09	.10±.10	.07±.10	.37±.09	.08±.10

Table II gives the inter-correlations between each of the six pairs of the members of the body, namely, Right Arm-Left Arm, Right Finger-Left Finger, Right Arm-Right Finger, Right Arm-Left Finger, Left Arm-Right Finger, and Left Arm-Left Finger, in respect of the ten quantitative aspects of the ergogram. The first column lists each of the ten quantitative measures. The second column gives the correlation for each of these measures as they were observed on the right arm and the left arm. Column three treats the relationship between the right finger and the left finger, column four between the right arm and the right finger, column five between the right arm and the left finger, column six between the left arm and the right finger, column seven between the left arm and the left finger. In the case of each coefficient of correlation the standard error follows immediately.

TABLE II-*a*

SHOWING THE ORDER OF MAGNITUDE OF CORRELATION BETWEEN MEMBERS FOR ALL VARIABLES STUDIED

1	2	3	4	5	6	7
Variables	Highest r's					Lowest r's
1. No. of Pulls	RA–LA	RF–LF	LA–LF	RA–LF	LA–RF	RA–RF
2. Total Work	RA–LA	RF–LF	RA–RF	LA–LF	RA–LF	LA–RF
3. % W. Q 1	RA–LA	RF–LF	LA–RF	RA–LF	LA–LF	RA–RF
4. % W. Q 2	RA–LA	RF–LF	LA–RF	RA–LF LA–LF	RA–LF LA–LF	RA–RF
5. % W. Q 3	RF–LF	LA–RF	RA–LF	RA–LA	LA–LF	RA–RF
6. % W. Q 4	RA–LA	RF–LF	RA–RF	LA–RF	RA–LF	LA–LF
7. % W. 1st Half	LA–RF	RA–LA	RF–LF	RA–LF	LA–LF	RA–RF
8. % W. Upper Half	LA–LF	LA–RF	RA–LA	RA–LF	RF–LF RA–RF	RF–LF RA–RF
9. Mean Succ. Var.	RA–LA	RF–LF	RA–LF	LA–LF	LA–RF	RA–RF
10. S.D. of Var.	RA–LA	LA–RF	RF–LF	RA–RF	LA–LF	RA–LF

In order to make Table II easier of analysis, Table II-*a* was prepared. In Table II-*a* the first column lists the variables under investigation. The remaining columns list the order with respect to magnitude in which the various combinations of members appear in Table II. In column two, for example, appear those pairs of members which yield the highest correlations in the case of each of the variables. In column seven appear the pairs of members which yield the lowest correlations in the case of each of the variables.

Examination of the results of Table II reveals a number of significant facts. On the whole, the measures obtained from the ergographic records exhibit statistically significant correlation for all variables listed in Column I except the Mean and the Standard Deviation of the Variations from stroke to stroke. As to the low order of the correlation coefficients obtained in the case of the Mean and Standard Deviation of the successive variations, it will be observed that in seven out of twelve coefficients, the correlation reported is while low, yet statistically significant.

Inspection of the results by columns in Table II and in Table II-*a* shows that in general the correlation coefficients for the RA–LA and for the RF–LF have the highest values. The correlation between the measures obtained on the comparable members of the body tends to

be higher than the correlation between the measures obtained from the members on the same side of the body or from non-comparable members on opposite sides of the body. Comparison of columns 2 and 3 indicates that there is in general a slight superiority in similarity in the case of arm ergograms over finger ergograms. The arm ergograms are slightly more similar on all measures but one (percent of work in Q 3) than are the finger ergograms. Finally it might be pointed out that a tendency is observed for RA–RF and LA–LF ergograms to be least similar, although the assertion is controverted in a number of instances.[2]

Examination of Table II by rows shows that of the ten variables studied, high correlations were obtained in the case of the total amount of work done by each subject, next to the highest correlations observed in the case of the number of pulls constituting the record. In view of the relatively large values involved, the observation is particularly significant. The values taken together suggest considerable consistency of individual output so far as physical work is concerned.

An interesting thing to be seen in Table II is the fact that the greatest consistency among the ergograms from the point of view of the quarters studied occurs in the case of the final quarter, in which case the coefficient is highest on three comparisons (RA–LA, RF–LF, RA–RF) and second highest on the remaining three (RA–LF, LA–RF, and LA–LF). As a matter of fact, in some instances the fourth quarter exhibits greater stability than the half of the ergogram.

Even the most casual inspection of Table II cannot fail to suggest the possibility of the existence of a general tendency for records taken from different members of the same person to be more alike than they should be by chance. Whether this is so in the case of any one variable might be put to test by reducing the four distributions of that variable to measures in standard form, and then observing whether the variability of the four measures taken from the same person was on the average less than unity (the variability in each of the four distributions when the raw measures of amount of work done are transformed into standard measures). This procedure would follow closely the technique used by Hull (5) in his study of trait variability. In this instance the traits under investigation would be given by the measures of the variable under consideration as taken from the right arm, left arm, right finger, and left finger of the same person.

Preston (11) has recently shown that the mean of the distribution of trait variances, each variance taken from one of N subjects, can be

[2] It must be remembered that the comparison of the arm and finger ergograms involves not only a change in the member but also a change in the demand made upon the S, since the weight offered the S using the arm was 8.5 Kg. and using the finger was 2.5 Kg.

calculated directly from the intercorrelations of the traits by the formula:

$$\bar{V} = 1 - \frac{1}{n} - \frac{1}{n^2}\left[\sum_{j \neq k} r_{jk}\right]$$

and that the variance of the distribution of variances is given by:

$$V_v = \frac{(2n-2)}{n^2} - \frac{4}{n^3}\sum_{j \neq k} r_{jk} + \frac{2}{n^4}[n^2 - 2n + 2]\sum_{j \neq k} r^2_{jk} + \frac{8(2-n)}{n^4}[r_{jk}r_{jp} + r_{jk}r_{jq} + \cdots] + \frac{16}{n^4}[r_{jk}r_{pq} + r_{jp}r_{kq} + r_{jq}r_{pk} +].$$

These formulae have been derived on the assumption that n (the number of traits, in this case 4) is a sufficiently large number. Only slight modification of the formulae is necessary to take the fact that n is small into consideration, since by the theory of small samples (4), one may take $(n - 1)$ for n in the divisor of the formula for the variance in order to be certain that the variance is not underestimated. There being a sufficiently large number of *Ss* (100 in this investigation), V_v will be affected only to the extent that n is replaced by $(n - 1)$ in the expression for V_i (the variance of the individual *S*).

Accordingly, making the replacement we have

$$\bar{V}^1 = 1 - \frac{1}{n(n-1)}\sum_{j \neq k} r_{jk}$$

$$V'_v = \frac{2}{n-1} - \frac{4}{n(n-1)^2}\sum_{j \neq k} r_{jk} + \frac{2(n^2 - 2n + 2)}{n^2(n-1)^2}\sum_{j \neq k} r^2_{jk} + \frac{8(2-n)}{n^2(n-1)^2}[r_{jk}r_{jp} + r_{jk}r_{jq} + \cdots] + \frac{16}{n^2(n-1)^2}[r_{jk}r_{pq} + r_{jp}r_{kq} + r_{jq}r_{pk} + \cdots],$$

in which the primed quantities are defined to take into account the fact that V_i is based upon a small sample.[3]

Table III gives values of $\bar{V}^1$, $\sigma_v{}^1$ and $\sigma_{\bar{v}}{}^1$ based on the coefficients of correlation shown in Table II. Column 1 lists the ten aspects of the ergogram under study. Column 2 gives the mean of the trait variances for each variable. The value .417 was obtained by inserting the six coefficients in the first row of Table II into the formula for

[3] I am indebted to Professor Preston for the argument by which $\bar{V}^1$ and $V_v{}^1$ are defined.

TABLE III

GIVING THE MEAN OF THE TRAIT VARIANCES, THE VARIANCE OF THE TRAIT VARIANCES AND THE STANDARD ERROR OF THE MEAN TRAIT VARIANCE

Variable	$\bar{V}^1$	V_v^1	$\sigma_{\bar{v}}^1$
1. No. of Pulls	.417	.150	.039
2. Total Work	.532	.254	.050
3. % W. Q 1	.412	.118	.034
4. % W. Q 2	.655	.310	.056
5. % W. Q 3	.552	.207	.046
6. % W. Q 4	.392	.114	.034
7. % W. 1st Half	.355	.094	.031
8. % W. Upper Half	.502	.171	.041
9. Mean Succ. Var.	.662	.351	.059
10. S.D. of Var.	.778	.503	.071

$\bar{V}^1$. It should be remembered that the formula calls for each coefficient to appear twice. Column 3 gives the variance of the distribution of trait variances over the 100 *Ss* for each of the ten aspects of the ergogram under study. The value .150 was obtained by inserting the six coefficients of the first row of Table II into the formula for V_v^1. Examination of Table III indicates that for each of the ten characteristics of the ergogram under study, the variability among the four members from the same subject is on the average less than the variability of any one of the members among the 100 *Ss* of the experiment. This means that four records from the same person will probably be more alike than four records taken by chance, one from each of four different people. This similarity among the four members appears to be largest in the case of the percentage of work done in the first half and the percentage of work done in the last quarter of the working period. It will be observed that on the average the degree of similarity for number of pulls, % Quarter 1, % Quarter 4, % Half 1, and % Upper Half exceeds the similarity for the Total Work done. From this observation might be drawn the conclusion that the tendency to distribute the work over a given period in a given way appears to be more characteristic of the individual than does the tendency to do a given quantity of work.

Since N (the number of subjects) is a sufficiently large number, we may suppose that $\bar{V}^1$ distributes itself normally with a σ at $\frac{\sigma_v^1}{\sqrt{N}}$. On the basis of this assumption the standard error of $\bar{V}^1$ has been calculated and entered in Table III in Column 4. Inspection of the table discloses the fact that the means are highly reliable and that little variation could be expected to occur in them on the basis of sampling error. It is obvious by inspection that the differences between the means are also reliable. This expectation is further supported by the

fact that the σr of Table II, on the basis of which Table III has been constructed, are in general low.

The ten variables studied in Tables II and III may be classified into groups. Variable 1 (Number of Pulls) is determined by the length of time during which the *S* labors. As such it might be supposed to be affected in part by the *Ss* physical capacity and in part by the rate at which available energy is dissipated. Variable 2 (Amount of Work Done) is a measure which is strongly influenced by the *Ss* physical capacity. As such it might be supposed to be strongly affected by metabolic processes. Variables 3, 4, 5, 6, 7, and 8 (giving the percentage of work done in various fractions of the working period) are definitely not direct measures of physical capacity; rather they are to be regarded as measures which are affected by the *Ss* characteristic tendency to distribute his available energy over the temporal interval during which he labors. Variables 9 and 10 give measures which depend upon the regularity with which the *S* labors. As such they should not be directly affected by either the *Ss* physical capacity or the tendency to distribute energy in a characteristic fashion.

The fact that the tendency to distribute energy after a characteristic pattern is more pronounced than the tendency to yield a characteristic amount of work suggests an inquiry into the dependence of the one tendency upon the other. Table IV presents the results of such an inquiry.

TABLE IV

SHOWING THE EXTENT OF CORRELATION BETWEEN (*a*) THE NUMBER OF PULLS AND (*b*) THE TOTAL AMOUNT OF WORK ON ONE HAND AND THE REMAINING VARIABLES STUDIED ON THE OTHER, AS THE LATTER ARE SHOWN ON THE RIGHT ARM AND LEFT FINGER ERGOGRAMS

Variables Correlated	Right Arm	Left Finger
1. No. of Pulls—% Work Q 1	+.66±.08	+.57±.08
2. No. of Pulls—% Work Q 2	+.52±.09	+.08±.10
3. No. of Pulls—% Work Q 3	−.70±.07	−.53±.08
4. No. of Pulls—% Work Upper Half	−.54±.08	−.39±.09
5. No. of Pulls—the Mean Variat.	−.27±.10	−.20±.10
6. No. of Pulls—the S.D. Variat.	−.06±.10	−.11±.10
7. Total Work—% Work Q 1	+.10±.10	+.05±.10
8. Total Work—% Work Q 2	+.22±.10	−.04±.10
9. Total Work—% Work Q 3	−.07±.10	−.06±.10
10. Total Work—% Work Upper Half	−.10±.10	−.15±.10
11. Total Work—the Mean Variat.	−.01±.10	+.10±.10
12. Total Work—the S.D. Variat.	−.27±.10	+.10±.10

Table IV shows the correlation between the number of pulls on the right arm and (1) the percentage of work done in the first quarter

of the working period, (2) the percentage of work done in the second quarter, (3) the percentage of work done in the third quarter, (4) the percentage of work done in the upper half of the curve, (5) the means of successive variations, and (6) the S.D.'s of the successive variations, (the latter values being taken from the right arm ergograms) together with the correlations between the amount of work done by the right arm and the six measures just enumerated, the latter, of course, also being taken from the right arm ergograms. The same information is also given in this table in respect of the measures obtained on the left finger ergograms. In each case the standard error is attached to the coefficient of correlation.

Examination of Table IV reveals that so far as the measures obtained on the right arm are concerned, a significant correlation appears between the numbers of pulls, and (1) the percentage of work done in the first quarter of the working period, (positive), (2) the percentage of work done in the second quarter (positive), (3) the percentage of work done in the third quarter (negative), and (4) the percentage of work done in the upper half of the ergograms (negative). On the other hand, the correlations between the same items and the total work done are insignificant. Both facts just stated are confirmed by the study of the correlation as shown in Table IV on the left finger ergograms. Examination of Table IV in connection with the left finger shows that significant relationship is exhibited between the number of pulls and (*a*) the percentage of work done in the first quarter (positive), (*b*) the percentage of work done in the third quarter (negative), and (c) the percentage of work done in the upper part of the ergogram (negative). The remaining left-finger coefficients (including all those pertaining to the total amount of work done) exhibit no statistical significance. The fact that none of the variables, when correlated with the total amount of work done on either the right arm or the left finger, yield significant correlation suggests the probability that these variables are not measures of the physical capacity of the subject. The further conclusion as suggested by the results of the correlations between the number of pulls and the various fractions of the ergogram is that these latter items measure essentially the tendency of the subject to distribute her work in a given pattern. This conclusion is reinforced by the change of sign observed in the case of the third quarter as compared with the first and second. The conclusion is further suggested that the measures of work regularity are not functions of either the capacity for work or the tendency to distribute the work in a given way.

In order to verify the conclusion already supported by the results of Table IV, it was decided to test all variables on two of the members of the body (right arm and left finger) by correlating them against the

height-weight ratio of the subject. Johnson's study (5) of mental growth of children in relation to the rate of growth in bodily development concludes that physical strength of an individual is directly related to the height-weight index, while Smith (10) maintains that superior height and weight are associated with energy. Results of other investigators, too, suggest the same fact, namely that these two measures yield significant correlation with the subject's physical capacity. The use of Table V, therefore, was resorted to on the expectation that variables which were determined by the subject's capacity to resist fatigue would show relationship with the height-weight ratio, while those which were independent of the subject's capacity to resist fatigue would show no such relationship.

TABLE V

SHOWING THE CORRELATION BETWEEN THE HEIGHT-WEIGHT RATIO AND EACH OF THE VARIABLE ENUMERATED IN TABLE III AS THE LATTER ARE SHOWN ON RIGHT ARM AND LEFT FINGER ERGOGRAMS

Variables	Right Arm	Left Finger
1. Number of Pulls	−.18±.10	−.12±.10
2. Total Amount of Work	−.30±.09	−.21±.10
3. % of Work Q 1	−.05±.10	+.11±.10
4. % of Work Q 2	−.20±.10	+.10±.10
5. % of Work Q 3	+.03±.10	−.07±.10
6. % of Work Q 4	+.11±.10	−.13±.10
7. % of Work 1st Half	−.10±.10	+.14±.10
8. % of Work Upper Half	−.08±.10	+.01±.10
9. Mean of Variations	−.01±.10	−.15±.10
10. S. D. of Variations	+.06±.10	−.13±.10

Table V studies the correlation between the height-weight ratio and each of the variables enumerated in Table II in respect of the right arm and the left finger. In each case the standard error immediately follows the coefficient of correlation. It must be remembered in connection with the interpretation of the values observed in this table that a large height-weight ratio is obtained in the case of the tall, thin person while a small ratio is obtained in the case of the short, stocky person. Negative coefficients, therefore, indicate a tendency for the short, stocky person to be superior on the variables under consideration.

Examination of this table shows that in the case of the measures obtained on the right arm, as well as in the instance of those observed on the left finger, the total amount of work done by the subjects exhibits significant correlation (although very small) with the height-weight ratio. Furthermore the sign of the coefficient (negative) is appropriate to the expectation that the short, stocky person possesses

a greater physical capacity than the tall, thin person. The remaining items appear to have little or no significant relationship with it. While admittedly the crucial coefficient is small, the present observations are consistent with the theory that the way in which a subject distributes his work is not dependent upon his physical capacity to do work.

Discussion

We may summarize the analysis of Tables II, III, IV, and V in the statement that under the conditions of this experiment *Ss* tend to give records from four members of the body which are alike in respect of (1) tendency to give a characteristic amount of work, (2) tendency to distribute the work in a characteristic pattern and (3) tendency to work according to a characteristically irregular tempo. In addition, we may point out that it is quite clear that the second and third of these tendencies are independent of the first.

The present experiment does not permit of a choice between the various hypotheses which might be offered to account for these latter two tendencies. Among the facts which are required and the study of which must be left to other experimentation are those which depend upon variation in the conditions of the experiment. To decide, for example, whether these phenomena are a result of self-instruction (explicit conscious verbalization) requires the study of records taken under conditions in which the instructions are varied. To decide whether the results are a function of some fortunate selection of the weights used, obviously the weights should be varied. If the results are construed as a phenomenon of a constant level of incentive self-supplied (the operation of which the industrial psychologists sometimes refer to as the will to work), that conclusion must flow from the introduction of suitable variation in the incentives offered the worker. If the hypothesis is entertained that the results are a consequence of the records all being taken from the same level of fatigue, obviously records are required which were taken at different fatigue levels. Finally, we may point out that the taking of records, one each on differing days, would throw light on the consistency with which these latter tendencies are operating.

For the present we must content ourselves in pointing out that we do not regard it as likely that the *Ss* of the present experiment were governed by explicit self-instruction at the level of conscious verbalization. In the first place, the formal instructions were read to the *S* four times, a fact which suggests that the *Ss* could have been in little doubt concerning their duties. In the second place, collateral unpublished research by Preston (undertaken in connection with laboratory work in experimental psychology) indicates that *Ss* learn with

surprise that the ergograms disclose a tendency to distribute the effort in a characteristic fashion.

We are also not inclined to the view that the results are explainable on the hypothesis that the *Ss* furnished their own level of incentive, that the tendencies under observation here are a result of the characteristic will to work of the individual *Ss*. Such a theory is better fitted to account for the tendency to dissipate a characteristic *amount* of energy than to account for the tendency to dissipate the energy in pattern characteristic of the *S*.

Summary

1. Using a weight ergograph, four ergograms were taken from each of one hundred female subjects, namely, (*a*) on the right arm, (*b*) on the left arm, (*c*) on the right middle finger, and (*d*) on the left middle finger.

2. The variables studied in each ergogram were: the Number of Pulls, the Total amount of work done, the percent of work done in the first quarter of the working period, the percent of work done in the second quarter, the percent of work done in the third quarter, the percent of work done in the fourth quarter, the percent of work done in the first half of the working period, the percent of work done in the upper half of the ergogram, the Mean of the successive variations, and the Standard Deviation of the successive variations.

3. The intercorrelation of the measures obtained from every subject for each variable enumerated above was found statistically significant for 55 of the 60 items (see Table II). The exceptions occur in the case of the Mean of the successive variations and the Standard Deviation of the successive variations.

4. The coefficients of correlation observed using Number of Pulls and Total Amount of Work in general are higher than the measures obtained using the remaining variables studied, the Total Work exhibiting the highest correlation (see Table II).

5. Correlation between the measures obtained from the ergographic records of the cross-members of the body (like the Right Arm and the Left Arm, or the Right Middle Finger and the Left Middle Finger) tends in general to be higher than the correlation between the measures observed on the ergograms of the members found on the same side of the body.

6. The correlation also tends to be high for similar members found on different sides of the body (RA-LA or RF-LF) and to be low for dissimilar members whether the latter are found on the same or on different sides of the body (like LA-RF or LA-LF) as seen from Table II.

7. A study of the variability among the four ergograms taken from the same person indicates that in the case of every variable studied it is, on the average, less than the variability of the ergograms over the 100 *Ss* of the experiment. The variability in general appears to be less among the variables reflecting the *Ss* tendency to distribute his energies in a characteristic fashion than in the case of total work done.

8. The Number of Pulls show relationship with the variables defining the pattern of performance, whereas the Total Amount of Work done exhibits no significant relationship with those variables.

9. The Total Amount of Work shows significant low correlation with the Height-Weight Ratio, the remaining variables show no significant correlation.

10. The final quarter of the ergogram appears to exhibit greater constancy from member to member than any of the other three quarters.

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THE RELATION OF TRANSFER TO SIMILARITY IN HABIT-STRUCTURE [1]

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Introduction

The experiments to be reported are most directly related to the problem of similarity as a variable in influencing transfer. In dealing with similarity, these experiments involve a distinction between different aspects or levels of a habit-system, superordinate and subordinate, and, hence, they make contact with the long-standing controversy over transfer of 'method' and transfer of 'identical elements.' In a broader manner, the present experiments concern the general problem of the complex structure of habit-systems, relations between superordinate and subordinate aspects of such systems, and the functional interrelations of differently structured systems. These experiments, then, concern some of the most difficult problems in the field of learning, problems which raise fundamental issues for any general theory of learning.

To provide a background for understanding the present experiments, it seems desirable to discuss in advance some of the special features involved. Three features of the present research distinguish it from the previous work on transfer and similarity.

First, an attempt is made to deal more completely with the problem of transfer by taking into account more than a single aspect or level of a habit-system in defining inter-habit relationships and in measuring transfer phenomena. As applied both to learning and to transfer, the concept of similarity refers to a highly complex set of relationships between successive activities. Complete treatment of the problem of similarity would, therefore, require definition and identification of the different aspects in respect to which inter-task relationships may vary, and would necessitate consideration of the complex structure of habit-systems. In both theoretical and experimental treatments of learning and transfer it has become the custom to avoid involvement in the problem of describing completely the habit-systems concerned and to limit consideration to a single aspect, usually a subordinate aspect such as the stimuli or the specific responses.

[1] This is part of an investigation presented to the Faculty of the Graduate School of Yale University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in psychology.

Actually any description of the relationship between successive trials or tasks contains an implicit assumption in respect to the nature of the activity or habit-structure involved. In descriptions of learning, for example, the 'sameness' of the activity in the various repetitions is usually limited to certain aspects (*e.g.* the goal, the task, or the situation) while the activity differs markedly in other aspects (*e.g.* the method or the particular responses). Similarly, in descriptions of transfer, the 'difference' between two tasks is limited to certain aspects (*e.g.* the situation or the materials) while the two tasks are the same in other aspects.

Difficulties related to the broader problem arise even when the attempt is made to deal only with the simplest subordinate aspects of a habit-system. When, for example, the attempt is made to study transfer by varying only a simple aspect of the stimuli or the materials, the use of a term such as 'equivalence' is often found necessary. Equivalence in these cases commonly refers to functional similarity with respect to a broader aspect, the 'goal,' the 'task,' or the 'method.' The solution in terms of equivalent stimuli or responses often begs the question since the equivalence, itself a form of transfer, still remains to be described and explained.

Since the relationship between successive trials in learning and between successive tasks in transfer is seldom completely defined, the terms 'habit-system' and 'habit-structure,' although of frequent occurrence in the literature on learning, are strikingly lacking in precise definition and systematic meaning. They refer broadly to larger, superordinate (higher-order) units within which smaller, more specific, subordinate units are incorporated. Often they are used in connection with a somewhat complex or extended performance within which the separate acts are supposed to share the influence of a common factor, the task, *Aufgabe*, or method of solution. It has been much easier to infer the existence of such higher-order units when theorizing than it has been to demonstrate concrete characteristics or influences of such units.

Although none of the theoretical approaches to learning offers a ready solution to the problem of dealing with the different aspects (levels) of an activity or habit-system, all of the approaches recognize the need of concepts to describe the complex nature of habit-systems. The concepts offered by the various systematic approaches are naturally different, in consistency with the theoretical systems involved. Hull offers the concept of the "habit-family hierarchy" which represents a combination of his concepts of divergent and convergent excitatory tendencies.[2] Tolman offers the concept of "means-end-field" which represents a hierarchy of superordinate and subordinate goals or demands, in consistency with his motivational approach to learning.[3] Lewin stresses such concepts as the 'activity-structure' and the 'action-whole,' distinguishing between superordinate and subordinate aspects of such structures. Lewin draws a sharp distinction between such superordinate aspects as wants or needs (*Bedürfnis*) and other types of superordinate aspects such as modes of execution or methods of procedure (*Ausführungshandlung*).[4]

In the experiments to follow a habit-system is conceived of in terms of a hierarchy of superordinate and subordinate segments of directed activity. The term 'hierarchy' is used in the accepted sense of a complex organization of habits in which habits of a higher order include as components those of a next lower order. The terms 'super-

[2] HULL, C. L., The concept of the habit-family hierarchy and maze learning. *Psychol. Rev.*, 1934, 41, 33–52, 134–152.

[3] TOLMAN, E. C., *Purposive behavior in animals and men*, New York: Century, 1932, pp. 37, 446, 450.

[4] LEWIN, K., Vorsatz, Wille, und Bedürfnis (mit Vorbemerkungen über die psychischen Kräfte und Energien und die Struktur der Seele), *Psychol. Forsch.*, 1926, 7, 294–385.

ordinate' and 'subordinate' are used to refer merely to degrees of inclusiveness, and are defined more strictly in terms of the specific activity-operations involved.

The particular habit-system chosen for study is a form of code-learning (letter-digit substitution) in which the response to each digit-stimulus is a directional manual movement to a certain position designated by a letter. Two different codes are used to constitute the two successive learning tasks. Within this task of code-learning each simple reaction-movement related to its single digit-stimulus is regarded as a subordinate unit. A superordinate level of units is provided by presenting the digit-stimuli in groups of five, and by requiring the subject to combine these five simple subordinate units into larger units in a prescribed serial order. Variation of the activity at the superordinate level can be produced by prescribing different serial orders of reaction with respect to the spatial arrangement of the five stimulus-items.

A second point of difference from previous work on transfer and similarity is the fact that in the present experiments variation in the similarity-relationship between tasks is introduced at a superordinate rather than at a subordinate level. Experimentally, this means that the superordinate serial order of response is varied in similarity from group to group, whereas the change in code is kept constant for all groups. Three different degrees of superordinate similarity between the two successive tasks are chosen for study: complete identity of serial order, mere similarity of serial order, and extreme difference in serial order. When the similarity relation is varied at this higher level, it is possible to study various types of transfer phenomena. One can study the effects of transfer at the separate levels, superordinate and subordinate, and one can obtain information upon the functional interrelation of these two levels. These phenomena bear directly upon the larger problems concerning the functional interrelations within single habit-systems and between differently structured systems.

The procedure in the present experiment presents, then, a direct contrast to that of the conventional experiments on transfer in which superordinate aspects of the two successive tasks studied are usually kept identical while some subordinate aspect is varied in similarity. Although numerous previous researches have clearly demonstrated the importance of superordinate aspects of activity such as the goal, task, or method in determining transfer, they have not been concerned directly with variation of superordinate similarity.[5]

[5] A brief summary of the experiments showing the influence of method and instructions upon transfer is available in Woodworth, R. S., *Experimental psychology*, New York: Henry Holt, 1938, p. 205 ff. The following attempts to deal with the similarity of maze-patterns are most

Finally, most of the experimentation on transfer has been concerned merely with measurement of the gross effects of inter-task influences upon the efficiency of performance and has contributed relatively little to an understanding of the processes involved. The interest in the present experiments is in relating such gross transfer-effects to actual underlying processes. It is assumed that the nature of these underlying processes will most likely be revealed by direct study of the actual responses carried over from one performance to another, by the study of *transfer proper*, rather than of *transfer-effects*.[6] In order to identify and measure such direct carry-over, this study is limited to cases in which the transferred items, termed *reversions*, constitute errors in the later performance. Utilization of the special technique previously devised by the author to deal with partial as well as complete reversion-errors should make it possible to detect and measure whatever inter-habit phenomena occur and to identify the habit-unit responsible for the effects.[7]

The specific problem of the present experiments is, then, that of varying similarity in the superordinate aspect of two successive tasks and measuring the effects both in terms of gross transfer-effects and specific reversion phenomena. A single straightforward experiment would suffice if one were to measure the transfer merely in conventional terms of gross effects upon the rate of learning. But if one wishes also to measure the actual reversion phenomena, the problem is complicated by the fact that reversions can occur at two levels of the habit-structure—at the superordinate serial order level and at the subordinate code level. Since technical difficulties make it impossible to detect accurately both types of reversion-errors in a single experiment, three separate experiments are required, each devoted to a special type of measurement. In Experiment I the gross transfer-effects, reflecting the combined effect of reversion phenomena at both the superordinate and subordinate level, are studied. In Experiment II, superordinate phenomena (serial-order reversions) are isolated for study, and in Experiment III subordinate phenomena (code reversions) are isolated for study. Experiments II and III, then, represent an analysis of the reversion-phenomena responsible for the gross transfer-effects in Experiment I.

directly related to the present problems: BARKER, R. G., Factors influencing transfer between finger mazes, *J. genet. Psychol.*, 1933, 6–7, 115–130; MACCOLL, S. H., The relation of transfer in maze learning to similarity of pattern, Unpublished Master's Thesis, Smith College, 1934; SHOWALTER, D. F., A qualitative analysis of the learning of human subjects on variable pattern mazes, *Psychol. Monogr.*, 1933, 167–194.

[6] The distinction between transfer proper and transfer-effects has been utilized by WOODWORTH, R. S., *Op. cit.*, pp. 176 ff., and by SIIPOLA, E. S., Implicit or partial reversion-errors: a technique of measurement and its relation to other measures of transfer, *J. Exp. Psychol.*, 1940, 26, p. 53. The terminology suggested in the author's previous article will be adopted here throughout.

[7] *Op. cit.*

Apparatus and General Method

The apparatus and technique previously devised by the author for the detection and measurement of partial reversion-errors were utilized in these experiments. Since these have already been fully described in a previous publication, only a brief summary of the technique common to all three of the present experiments will be given here.[8] Details of the specific procedure will be given in connection with each of the experiments.

Experimental Situation.—The subject was seated in front of a horizontal reaction-plate providing an open semicircular reaction-area within which a lever could move freely, and along the curved periphery of which 20 regularly spaced radial slots provided terminal positions for the different code-reactions. The task of the subject was that of motor code-substitution in which he had to respond to any one of ten number-stimuli by moving the lever to an assigned reaction slot designated by a letter. The stimuli were typed Arabic numbers, and the designations of the slots on the reaction-plate were capital letters. All twenty slots were labelled for use by assigning letters from A to W in alphabetical order beginning from the left. (Letters J, Q, and V were not used.)

For each reaction-trial a series of five stimulus numbers (*e.g.*, 6 2 8 9 4) appeared in the exposure area, and the task for the subject was that of reacting with the five appropriate movements of the lever in succession according to the serial-order prescribed. The combining within a single trial of five reaction-items (five simultaneously exposed stimuli and five reaction-movements) made possible the desired variation of a superordinate aspect of the task, namely the temporal order of reaction-movements. This feature also served to encourage the production of a very rapid sequence of movements.

Exposure of the stimuli was controlled by a disc shutter behind an aperture in the screen facing the subject. Reaction-time (from exposure of the stimulus to completion of the fifth reaction-movement) was measured by means of a Springfield timer. In each trial the five-number stimulus remained exposed until the subject closed the shutter by his final return to the starting position after the fifth movement. The next trial followed immediately, preceded by a ready-signal. Rest periods of one minute were provided after each ten trials. The two consecutive learning tasks were separated by an interval of 5 minutes; this interval was occupied completely by the noting of introspective comments on Task A and the giving of the new instructions for Task B.

In order to standardize the procedure and timing during the learning of the motor code, a mechanical means for prompting was provided. The reaction-plate included a prompting sector with contact points. Bringing the lever into contact with the point marked for a given stimulus revealed, by illumination from below, the designation of the appropriate reaction-slot. In order to discourage continued reliance upon prompting, a delay of five seconds before prompting would occur was mechanically provided.

Method of Recording.[9]—A complete 'literal' tracing of the path of movement for each reaction was secured by means of a system of direct mechanical connections between the extended lower end of the reaction-lever and a distant writing point. The subject was kept unaware of the fact that his movements were being recorded. The reading and analysis of the records was accomplished by placing the tracings over an accurate ground glass "map" constructed from actual tracings of the lever movements. Measurements of variations in the paths of movement from the direct path were made in angular units.

Experiment I

The Influence of Superordinate Similarity upon Gross Transfer-Effects

This experiment was designed to investigate the influence of variation of the similarity relation between habits at a superordinate level upon transfer as reflected in the usual gross measures of transfer-

[8] Siipola, *op. cit.*

[9] Detailed descriptions of the recording device, the type of record obtained, and the method of measuring degree of error are included in the previous paper. Siipola, *op. cit.*, pp. 57–62.

effects. Both the superordinate serial order and the subordinate motor code were changed in the second task so that the gross transfer measures reflect the combined effect of reversion phenomena at both the superordinate and subordinate levels. The plan here is that of disregarding the specific nature of possible reversion phenomena while dealing with their gross effects upon the rate of learning in the second task.

Procedure.—The general plan of arrangement of the experimental groups is given in Table 1. Three groups (I, S, and D) were used. The only factor varied from group to group was the serial order prescribed in Task A.

TABLE 1

GENERAL PLAN OF EXPERIMENT I

	Task A (Code x)	*Task B (Code y)*	*Retest Task A*
Group I	Reaction to stimuli in 34521-order according to position reading from left. (Order identical to that of Task B.) Example: stim. = 37942 resp. = IDNGB	Reaction to stimuli in 34521-order according to position. Example: stim. = 37942 resp. = ATCRM	Same as Task A
Group S	Reaction to stimuli in 32145-order according to position. (Order similar to that of Task B.) Example: stim. = 37942 resp. = IGBDN	Same as above	Same as Task A
Group D	Reaction to stimuli in order of numerical value; first the lowest number, then the next lowest, and so on. (Order dissimilar to that of Task B.) Example: stim. = 37942 resp. = NBDGI	Same as above	Same as Task A

Code x		*Code y*	
Stimulus	*Assigned Slot*	*Stimulus*	*Assigned Slot*
1 =	E	1 =	O
2 =	N	2 =	C
3 =	B	3 =	M
4 =	D	4 =	T
5 =	W	5 =	H
6 =	L	6 =	U
7 =	G	7 =	R
8 =	P	8 =	F
9 =	I	9 =	A
10 =	S	10 =	K

The three serial arrangements prescribed in Task A (see plan above) bear different relations to the arrangement prescribed in Task B. Roughly, the relation varies from one of identity for Group I, through one of similarity for Group S, to one of difference in kind for Group D. For Group I both the kind of order, one based upon spatial position of the stimulus-items, and the precise serial arrangement required remain the same. For Group S the method of arrangement is in both tasks one based upon spatial position of the stimulus-items, but for this group the precise serial arrangement required is different in the two tasks, although even here there is similarity

in that both orders start with the same, third item and proceed within the same general spatial pattern. For Group D the order prescribed in Task A involves a clearly different principle or method of arrangement. Here the reference is to a numerical scale rather than to a spatial schema, and the resultant specific arrangements may start with an item in any spatial position and proceed according to no consistent spatial pattern.

The determination of what orders would be related to the order of the second task in the manner of similarity and dissimilarity was made primarily upon a basis of common-sense considerations. It was not intended here to try to produce precise degrees of variation along a single dimension of similarity. Rather, it was hoped that three clearly differentiable relations could be found corresponding roughly to three main points among the manifold variations in similarity. In the aspect of the psychological operations required, the two tasks were identical for Group I. For Group S the operations remained the same in kind but involved a minor variation in detailed application. For Group D an entirely different and dissimilar kind of operation was required, based upon a different point of reference. Comments of the subjects indicated that the two tasks in each case were phenomenally related in the manner intended. Such rough and arbitrary determination of stages of similarity seems adequate for the purposes of this experiment. Attempt at a more refined means of measuring degrees of similarity would involve insuperable difficulties similar to those already encountered in attempts to define similarity in precise spatial-temporal terms for maze patterns.

Experimental Series.—In Task A the subjects learned to react by the correct movements (according to Code x) in the prescribed order until they reached a stage of three perfect trials in succession. The average number of trials required to reach this stage was 20. In each trial there were 5 stimulus-numbers, and these numbers were so selected that all 10 of the stimulus-numbers of the code were used in every two trials. The number of repetitions for each stimulus was, then, the number of trials divided by two.

In Task B the subjects were given 40 trials (providing 20 repetitions for each stimulus-number) which brought them to a stage of learning beyond that reached in Task A.

In the retest of Task A, trials were continued until a perfect trial appeared. An interval of 5 minutes intervened between Task A and Task B and again between Task B and the retest of Task A.

Instructions.—The subject was given careful instructions concerning the use of the apparatus and the use of the prompting sector. Preliminary practice in using the apparatus was provided by presenting letters in groups of five as stimuli which the subject 'copied' in the prescribed order of Task A. Twenty such preliminary trials (including 5 practice movements to each of the 20 slots) were given.

The code was learned by use of the prompting sector during the early trials. As soon as the subject had learned the correct letter (designating the reaction-slot) for a given number, he omitted the excursion into the prompting sector. Return to the starting position after each reaction to a stimulus-number was always required. It was explained to the subject that as soon as he had made contact with the end of any one of the reaction-slots, his reaction to the particular stimulus-number concerned was considered complete, and that no further correction was allowed. This instruction was essential to insure the presence in the record for each trial of five, and only five, distinct item-reactions. The timer ran continuously from the appearance of the stimulus until the final return to the starting position after the fifth reaction-movement.

Beyond the instructions as to the use of the apparatus and the serial order of reacting, the subject was told that the experiment concerned the learning of a code in which the stimulus-numbers, 1–10, were to be associated with certain letters designating movements. He was told that his learning would be complete when he was able to produce three successive perfect trials. At the start he was told to emphasize the accuracy and correctness of his movements and to try to get along without use of the prompting sector as soon as possible. (This instruction was necessary to insure accurate learning of the code during Task A.) In the later trials, the subject was encouraged to place the emphasis upon speed, and to reinforce this emphasis he was told his time-score after each trial. No mention was ever made of errors or inaccuracies. The subject remained completely oblivious to his paths of movement before entering a reaction-slot and to the fact that a record of these paths was being made.

In the interval between the two tasks, the instructions consisted in telling the subject that the code would now be changed, and in explaining fully the new serial order of reactions for each trial. To insure clear understanding of the new task, the subject repeated the instructions. No preliminary practice in the order and code of Task B was allowed.

Subjects.—Between 10 and 15 subjects, all right-handed, served in each of the groups. They were Smith College students selected at random from a large elementary class in psychology. Since it was necessary that the three groups be equated approximately in learning ability, enough subjects were used to provide 10 in each group equated to those of the other groups. The number of trials and the total time required to learn Task A to the prescribed stage were taken as the measures of learning ability (see Table 1). The final treatment of the results is based upon 30 subjects, 10 in each of the equated groups.

Results

The results are summarized in Table 2. In terms of both the total times and the total trials required to learn Task B to the stage of three successive perfect trials, the results agree in all cases to show

TABLE 2

Learning Scores in Time and Trials

	Total Trials for Learning (to 3 perfect trials)					Total Time in secs. for Learning (to 3 perfect trials)					Reaction-Time in secs. (40 trials)	Re-learning Scores (to 1 perfect trial)	
	Task A	Task B				Task A	Task B				Task B	Re-test Task A	
	Mean	Mean	S.D.	S.D.M	Transfer	Mean	Mean	S.D.	S.D.M	Transfer	Mean	Mean Trials	Mean Time
Group I	20.7	15.7	4.1	1.4	+24.2%	617.4	407.0	88.7	31.4	+34.1%	17.7	6.3	156.8
Group S	21.2	20.2	4.9	1.7	+ 4.7%	612.2	498.0	63.4	22.4	+18.7%	19.4	7.0	201.8
Group D	20.3	11.5	2.0	0.7	+43.9%	603.5	352.7	55.0	19.5	+39.6%	16.8	4.0	110.1

a positive, rather than a negative, transfer-effect, ranging in amount from 5 percent to 44 percent. The results for individual subjects support this finding of positive transfer. On the basis of both time- and trial-scores, 24 of the 30 subjects showed positive transfer and only 6 negative transfer. Apparently, factors (such as familiarity with the broad nature of the task) working in the positive direction completely overshadowed the negative influence of reversions in determining the learning-scores. That a great many reversion-errors were present in this experiment was obvious from even a casual inspection of the recorded paths of movement.

In the present experiment in which reversions of both the code-type and the order-type might occur, it was impossible to apply the criteria and measurements for reversion developed in the later experiments which allow in each case only one type of reversion to occur. The measurements developed later involve the defining of a 'critical' slot and the counting of deviations of unusual magnitude toward this slot as reversions. In the present experiment, with two such critical slots to be considered for a given reaction (one for code-reversion and one for order-reversion) and with two sets of measurements to be made, the procedure becomes so complicated as to be impracticable. Moreover, the two critical slots might be so placed as to lead only to indecisive results.

In the case of Group I, the difficulty described above does not arise since in this case only a single type of reversion, code-reversion, was possible. According to the method of measurement to be used later, Group I showed for the 40 trials of Task B 34 percent reversion-errors. This figure means that more than one-third of the movements showed a code-reversion tendency despite the fact that the gross transfer-effect is positive. This large discrepancy between measures of transfer-effect and reversions corroborates our previous findings.[10]

The important question, here, however, is not one of the direction of the transfer-effect, but rather one of the relative amounts of transfer shown by the three groups. In respect to the relative amounts of positive transfer shown, the order of the three groups is consistent for both measures of transfer, trials and time. Group D had most positive tranfer (40 percent–44 percent), Group I an intermediate amount (24 percent–34 percent), and Group S the least (5 percent–19 percent). The same order of the groups holds when the mean reaction-times for the 40 trials in Task B are compared. Moreover, even the order of the groups in respect to the difficulty in relearning Task A remains consistent.[11]

Throughout the results, then, one finds that variation of superordinate similarity has a definite and a consistent effect upon gross transfer measures. With code conditions held constant for all groups, change to a widely dissimilar serial order produced most positive transfer-effect, continuation with the identical serial order an intermediate amount, and change to a similar serial order the least. This relative order of the three groups seems dependable in view of the consistency of all of the results, even though the actual differences between the three groups are not statistically reliable in all cases.[12]

The interpretation of this somewhat surprising order of the three groups, as it comes out here so consistently, is indeed difficult. That change to a widely dissimilar serial order should actually produce more positive transfer-effect than continuation with the identical serial order or change to a similar serial order is certainly not predictable from any of the conventional theories of transfer. An experimental analysis of the factors responsible for these results is, therefore, indicated. Within the gross measures used in the present experiment, two types or levels of reversion phenomena should be reflected: superordinate reversions to the previously learned serial order, and subordinate reversions to the previously learned code. If one knew the precise effect of varying superordinate similarity upon

[10] Siipola, *op. cit.*, p. 71.

[11] Comparison of the three groups in the relearning of Task A is of questionable significance since the stage of training reached in Task B was not controlled so as to be precisely the same for all subjects.

[12] The critical ratios for the mean number of trials required for learning Task B are: Group S, Group D, 4.6; Group S, Group I, 2.0; Group D, Group I, 2.6. The critical ratios for the mean time required for learning Task B are: Group S, Group D, 4.9; Group S, Group I, 2.4; Group D, Group I, 1.5. (With only 10 subjects in each group, N–2 rather than N was used in the calculation of the standard error of the mean. This procedure was also used in the later experiments.)

these two types of reversion-phenomena, one might have at least a partial explanation of these puzzling results. Further analytic experiments were, therefore, performed to discover the answers to these questions.

Experiment II

The Influence of Superordinate Similarity upon Superordinate Reversion-Phenomena

The purpose of this experiment was that of determining the relation between superordinate similarity and superordinate reversion-phenomena by isolating serial-order reversions and their effects upon reaction-time for study. The first point to be determined is whether reversions to the previously learned serial orders actually occur under the experimental conditions provided.[13] If such reversions do occur, one can then determine whether the frequency and transfer-effects of such reversions bear the same curious relationship to the degree of superordinate similarity as was found in the previous experiment. In order to isolate serial-order reversions and their effects from possible code-reversion phenomena, the occurrence of code reversions was prevented by using the same code in both of the successive learning tasks. Otherwise the experimental conditions were identical to those of the previous experiment.

TABLE 3

General Plan of Experiment II

	Task A (Code y)	Task B (Code y)
Group I	Reaction to stimuli in 34521-order. (Order identical to that of Task B)	Reaction to stimuli in 34521-order
Group S	Reaction to stimuli in 32145-order. (Order similar to that of Task B)	Same as above
Group D	Reaction to stimuli in order of numerical value. (Order dissimilar to that of Task B)	Same as above

Procedure.—The general plan of arrangement of the experimental groups is given in Table 3. The only factor varied from group to group was the serial order prescribed in Task A.

[13] Although the relation of superordinate similarity and superordinate transfer proper has not been previously investigated, there is ample experimental evidence to prove the actual carry-over of such superordinate aspects of performance as serial order. For example, Rees and Israel have demonstrated the carry-over of the serial order of anagram solution (the serial orders used were similar to those of the present experiment). An investigation of the establishment and operation of mental sets. *Psychol. Monogr.*, 1935, **46**, no. 210, 1–26. Reference to the carry-over of temporal or spatial patterns appears constantly in the literature on animal learning. See, for example, Gengerelli's study showing the carry-over of the spatial pattern of movement in a maze-situation. Studies in abstraction with the white rat. *J. genet. Psychol.*, 1930, **38**, 171–202.

Experimental Series.—The experimental series for Tasks A and B were identical to those of Experiment I. In Task A the subjects learned Code y until a stage of three successive perfect trials was reached. In Task B all subjects were given 40 trials. No re-test of Task A was given.

Instructions.—The instructions and preliminary training were again identical to those of Experiment I.

Subjects.—Between 10 and 15 subjects, all right-handed, served in each of the groups. The final treatment of the results is based upon the results for 30 subjects, three equated groups of 10 each. The number of trials required for the learning of Task A was taken as the measure of learning-ability, and the averages are 25.8, 26.1, and 25.2 for Groups I, S, and D respectively. The average time for the last five trials of Task A was used as the measure of speed, and the averages in seconds are 16.8, 16.2, and 17.2 for Groups I, S, and D respectively.

Results

Measurement of Serial-Order Reversions.—The analysis of the results here is based upon the detection of superordinate reversion-errors, returns to the previously learned serial order. At the outset it is obvious that for Group I a search for significant deviations toward the previously learned order is futile; in this case the two orders are identical and reversion 'errors' in Task B would necessarily coincide with the correct movements. In the case of the other two groups, S and D, the serial order of reacting learned in Task A is different from that required in Task B so that reversions here will appear as identifiable errors. For this type of analysis, then, the comparison is limited to one between Groups S and D. The question to be answered is that of whether previous training in a similar order produces more or fewer order-reversions than does training in a very different order of reacting. (Results for Group I become important in the later treatment according to reaction-time scores.)

One of the first points which comes out clearly in the analysis of the data is the relatively small number of complete reversion-errors (complete reproductions of all 5 items in the previously learned serial order). For all ten subjects in each group, each subject having 40 trials, the total numbers of complete reversions were only 21 and 2 for Groups S and D respectively. Comparison of these figures would point to a much stronger reversion-tendency in the case of Group S, but it seems doubtful that these figures reveal completely the extent to which reversion-phenomena were present. Therefore, measurement of partial reversion-errors (incomplete reproductions of the previously learned serial order) was carried out.

For the detection of partial reversion-errors in serial order an abbreviated type of analysis was found to be adequate. Preliminary study of the records showed that whenever a reversion in order occurred during a trial, the reversion-tendency was apparent in the reaction to the first decisive item in the trial. Hence, partial reversion-errors in order could be detected by determining whether the reaction to this first decisive item was consistent with the previously learned serial order. Such an analysis was made of the reactions to the decisive item in each of the 40 trials.

The decisive item for a given trial was the first in order for which the two different serial orders prescribed two different movements. In the case of Group D, this was ordinarily the

very first item of the five in a trial, since only occasionally did the lowest number appear in the position of third-from-the-left to make the same first reaction prescribed under either task. In the case of Group S, the decisive item was necessarily the second, since both tasks prescribed starting with the same middle number according to position.

In the treatment of these partial reversion-errors there is involved the assumption that the significant errors which occur are to be attributed to the single factor of serial-order confusion. This assumption was made upon the basis of the fact that the code remained the same in both tasks so that no inter-code errors were possible. There remains the possibility that some of the significant errors might actually represent intra-code confusions. Even if this is true, it in no way invalidates the method of treatment since the number of such intra-code errors should be constant for the different experimental groups. The absolute numbers of true order-errors may, however, be slightly lower than those given in each case.

The frequency of serial order reversions for Groups S and D is given in Table 4. Comparison of the means for complete and partial

TABLE 4

FREQUENCY OF SERIAL-ORDER REVERSIONS (40 TRIALS)

	Mean No. Complete Reversions	Mean No. Partial Reversions	Mean No. Complete + Partial	S.D.	$S.D._M$
Group S (10)	2.1	5.8	7.9	1.0	0.4
Group D (10)	0.2	2.9	3.1	0.8	0.3

reversions combined shows that Group S, which had learned a similar serial order in Task A, had a tendency to revert which was reliably stronger than that for Group D, which had learned a different kind of order in Task A; the critical ratio is 10.2. The reversion-tendency is relatively strong in the case of Group S (20 percent of the trials showed reversion) and is weak in the case of Group D (only 8 percent of the trials showed reversion). For both groups the majority of the reversions occurred during the first 20 trials with complete reversion likely to be shown in the first 2 trials. The separate figures for partial errors show that the use of this measure revealed a large number of 'hidden' order-errors.

These findings based upon reversion-errors lead, then, to the following conclusions. Reversions in a superordinate aspect of a habit do occur when, after training, a change in that aspect is required. Contrast between the case in which a slight change to a similar serial order was required and the case in which a more drastic change to a different principle of serial arrangement was required indicates that similarity between the two tasks increases greatly the frequency of reversion-errors.

For the statement of a general rule of the relationship between superordinate similarity and superordinate reversions the case of identity between tasks becomes crucial. The omission of Group I from the above comparison points to the following important fact.

In the study of *transfer proper*, the identification and measurement of transferred reactions are possible so long as these reactions constitute errors in the later performance. When, instead, the previously learned reactions are correct also in the later performance, the responses attributable to previous training can not be distinguished from those produced by the present situation. This creates a serious methodological difficulty in the study of transfer proper, since the variable of similarity cannot be treated in the region of identity without destroying the possibility of identifying and measuring the carry-over in terms of reversion-errors. This methodological difficulty will arise whenever measurement of reversion is made at the same level at which the variation in similarity is produced. In this experiment the difficulty arose because superordinate similarity was varied and reversion was measured at the same superordinate level. The same methodological difficulty would arise if subordinate similarity were varied and reversion were measured at the same subordinate level.

In so far as it is possible to theorize from other lines of evidence, there would seem to be no reason for concluding that the psychological process in the case of identity should follow a special rule. It is likely that the psychological process of return to (revival and utilization of) a previously learned reaction is essentially the same whether the result of it be improvement or the commission of an error. Whatever difference there may be in the actual process would arise from the complication of the mere process of revival by the presence of an attitudinal influence. In the one case which results in improvement the subject is hospitable to the revival of earlier reactions which are still correct, but in the other case the subject must guard against such revival to avoid errors. It might be reasoned, then, that in the case of identity all forty of the correct serial-order reactions in Task B should be scored as cases of return to the previously learned serial order. If this were done, the indeterminate case of identity would fall nicely into line with the trend shown by the other degrees of similarity for a direct relationship between superordinate similarity and superordinate transfer proper.

Measurement of Reaction-Time.—The reaction-time results, given in Table 5, are of especial interest in the case of this experiment since they allow the inclusion of Group I in a direct comparison of all three groups. The mean reaction-time per trial for Task B is highest for Group S (13.7 sec.), next highest for Group D (12.3 sec.), and lowest for Group I (10.6 sec.). The time-differences between Group I and the other two groups are clearly reliable; the difference between Group S and Group D, although smaller, is still fairly reliable according to the critical ratios in Table 5.

TABLE 5

MEAN REACTION-TIMES IN TASK B (40 TRIALS)

	Mean Reaction-Time in secs	S.D.	S.D.M	Critical Ratios
Group I (10)	10.6	.64	.23	Group I, Group S = 6.0
Group S (10)	13.7	1.28	.45	Group S, Group D = 2.6
Group D (10)	12.3	.72	.25	Group I, Group D = 5.1

Analysis of the influence of serial-order reversions upon reaction-time makes understandable the results obtained. In the case of both Group S and Group D, reversions to the previously learned serial order would produce decrement in speed, the decrement being larger for Group S which had the larger number of reversions. In the case of Group I, however, any reversion to the serial order of Task A would constitute a correct reaction and would therefore produce facilitation rather than decrement. Hence one would expect such relatively large differences as were found between Groups S and D on the one hand, and Group I on the other hand.

A fundamental point, implied by the above analysis, is that the methodological difficulty, encountered previously in dealing with a measure of reversion-errors for Group I, exists also in the case of the reaction-time measure. Reaction-time as a measure of *transfer proper* (carry-over) is as inapplicable to the case of identity as was the error measure. In the case of identity, which is in reality the case of ordinary learning, the conditions are such that carry-over of the serial order from previous training must increase, rather than reduce, the efficiency of performance in Task B. In the case of Groups S and D, on the other hand, carry-over of the serial order reduces the efficiency in Task B. The same criterion of *transfer-proper* (increase in reaction-time) cannot be applied to all three degrees of similarity. In order to bring the case of identity into relation with the other degrees of similarity, a shift in the criterion of transfer proper would be necessary. The amount of *transfer proper* in the case of Group I remains, then, indeterminate in so far as the experimental data are concerned.

With respect to *transfer-effect*, however, one can summarize the relation to superordinate similarity under the conditions of this experiment as follows: identity in superordinate aspects produces the greatest degree of efficiency (shortest reaction-time) in Task B, dissimilarity produces an intermediate degree of efficiency, and similarity the least. The trend of these results on similarity and transfer-effect is strikingly similar to the trend shown in the curve drawn by Robinson to represent the theoretical relationship between retroactive

inhibition and degree of similarity between original and interpolated activities.[14]

Such agreement might well be expected if, as seems likely, the processes involved in transfer and in retroactive inhibition are the same or closely related ones. A common feature of the two experiments, furthermore, is the use of a rough scale of similarity which does not correspond to systematic variations along a single dimension of similarity.

In the case of both experiments there is really a difference in the conception of similarity as applied to the first half and to the last half of the scale. In the region from identity to intermediate degree of similarity (from I to S) similarity is defined in terms of 'degrees of identity,' whereas the scale is continued on (to D) by introducing a new kind of variation, variation in 'degrees of difference' which may involve additional aspects of the tasks.

This point is confirmed by the fact that the theoretical relation postulated by Robinson has never been completely verified by any single experiment. Robinson himself was able to verify only the first half of the curve by varying the number of identical consonants in lists of consonants (by varying degrees of identity). Harden[15] later verified the second half of the curve by varying the number of items of a new class (digits) introduced into lists of consonants (by varying degrees of difference). Within the range of variation along a single dimension of similarity, either a fall or a rise in the curve occurs. The validity of the general shape of the composite curve rests upon the correctness with which the two separate dimensions are placed within a gross theoretical continuum reaching from complete identity to complete unrelatedness.

The preceding discussion implies that the familiar similarity-curve of Robinson and the results found here for *transfer-effect* do not represent the relation of similarity to reversion-tendency and *transfer proper*. Nor do they represent a general rule for all transfer-effect. Rather, the results present the case in which the transfer-effect happens to be measured under certain very special conditions: under conditions in which the aspect or level of the habit-structure isolated for study corresponds to the same level at which the variations in similarity are provided. The particular nature of these results is related to a shift in the applicability of the criterion of transfer in the region of the scale near identity. Such results on transfer-effect serve to conceal the nature of the essential phenomena of transfer proper, and they tend to make difficult the task of relating learning and transfer phenomena.

Of primary importance in this experiment is the finding that neither the results for serial order-reversions (transfer proper) nor their effects upon reaction-time (transfer-effect) will account for the surprising findings in Experiment I. In Experiment I (in which both the serial order and the code were changed in Task B) the order of the three groups in respect to positive transfer (from greatest to least) was: Group D, Group I, Group S. In the present experiment, in which serial-order reversions were isolated for study, the order of the three groups in respect to efficiency of performance in Task B (as measured by reaction-time) is: Group I, Group D, Group S. Interpre-

[14] ROBINSON, E. S., The similarity factor in retroaction, *Amer. J. Psychol.*, 1927, 39, 297–312.

[15] HARDEN, L. M., A quantitative study of the similarity factor in retroactive inhibition, *J. gen. Psychol.*, 1929, 2, 421–432.

tation of the results of Experiment I in terms of serial-order reversion is possible in the case of Group S which previously showed the miniml amount of gross positive transfer; in the present experiment this group had the greatest number of serial-order reversions and the highest reaction-time. But explanation in terms of order-reversion phenomena would clearly indicate the maximal amount of gross positive transfer for Group I rather than for Group D, which actually had the maximal amount in Experiment I. The fact that the gross transfer results of Experiment I cannot be fully accounted for in terms of superordinate transfer phenomena suggests that some factor operating in connection with subordinate transfer phenomena (code-reversions, which were possible in Experiment I) may also have to be taken into account. A still further experiment isolating the effects of superordinate similarity upon code-reversions is, therefore, indicated.

Experiment III

The Influence of Superordinate Similarity upon Subordinate Reversion-Phenomena

The purpose of this experiment was that of studying the relation between superordinate similarity and subordinate transfer proper by isolating code-reversions and their effects upon reaction-time for study. The primary question raised is that of whether similarity between superordinate aspects of two tasks (similarity in serial order, found effective in inducing serial-order reversion) has any consistent influence upon the occurrence of reversions at a subordinate level of the task (reversions to previously learned code-responses). Such influence is to be measured in terms of returns to specific movements required under an earlier code rather than in terms of order-reversions.

In order to achieve the purpose of this study, the two successive learning tasks must involve changes in both the superordinate aspect of serial order and the subordinate aspect of code-responses. However, it is essential to isolate the subordinate code-reversion phenomena from possible serial-order reversions by means of special experimental techniques. The changes required in serial order are those utilized in the previous experiments to provide three inter-task relationships varying in similarity from complete identity, through similarity to difference in kind. Change in the subordinate aspect was achieved by use of the two codes previously used in Experiment I. Since the change in the subordinate code-aspect was the same in all cases, subordinate code-reversion phenomena should be constant in all cases, unless such phenomena are not independent of, but are rather complicated by, the influence of superordinate relations. The question raised is essentially that of whether subordinate aspects of a

habit are functionally independent, or whether they are functionally interrelated parts of what might then be termed a common dynamic structure or system.

Procedure.—The general experimental conditions were the same as those of Experiment I with the introduction of the two following necessary changes in the experimental procedure: The same subjects were used in each case for the two serial orders to be compared in Task B; this was accomplished by requiring the subject to alternate between two serial orders in Task B. Secondly, reversions at the superordinate level were experimentally excluded by informing the subject in advance of each trial what order should be used. The primary question raised is therefore experimentally reformulated as follows: If Code x has been learned in Task A in connection with a certain serial order, and Code y is now to be learned in Task B in connection with two serial orders in alternation, will the frequency of reversions to Code x differ for the two Task B orders in dependence upon the similarity-relations which these orders bear to the order learned in Task A? The general plan of the experimental groups is given in Table 6.

TABLE 6

GENERAL PLAN OF EXPERIMENT III

	Task A (Code x)	Task B (Code y)
Group IS	Reaction to stimuli in 34521-order	Alternation between: 34521-order (identical to Task A) 32145-order (similar to Task A)
Group SD	Same as above	Alternation between: 32145-order (similar to Task A) Order of numerical value (dissimilar to Task A)
Group ID–1	Same as above	Alternation between: 34521-order (identical to Task A) Order of numerical value (dissimilar to Task A)
Group ID–2	Order of numerical value	Alternation between: 34521-order (dissimilar to Task A) Order of numerical value (identical to Task A)

The same subjects were required in Task B to alternate between the two serial orders, in order that the influence of such variables as the stage and rate of learning and speed of movement would not affect the comparisons. The necessity for taking account of these variables was made clearly apparent by preliminary experiments which revealed the marked influence of such factors upon reversion. Two possible methods of control are the use of the same subjects in both experimental series to be compared and the use of a very large number of different subjects. The former was adopted when a practical means of applying it was discovered, namely that of having the subject alternate between the different serial orders in Task B. This method provides the most direct and effective means for controlling the variables concerned. The more indirect means of employing large numbers of different subjects in the hope that individual differences would cancel out was impossible in this experiment for practical reasons. Analysis of the movement-records for each individual subject required from six to eight hours, an amount of time which is clearly prohibitive of the use of the large numbers of subjects which would have been necessary to secure reliably comparable groups.

From the purpose of the experiment the necessity of isolating subordinate reversion phenomena from possible superordinate reversions is obvious. In the final results, either in terms of paths of movement or time-scores, it would be impossible to distinguish effects of the two levels when both were possibly present. Hence, it was preferable to eliminate the superordinate reversion-tendency by the techniques of preliminary training to make the subject skillful in the use of either order, and announcement in advance of each trial of the order to be used. The reversion measures, then, should reflect the influence of only the subordinate type of reversions.

The general plan of arrangement of the experimental groups in Table 6 shows that the only factor which is different from group to group is the serial order prescribed for the reaction-movements within each trial. In Task A the serial order prescribed is the same for all groups except the group (ID–2) introduced to provide a control experiment. The serial orders prescribed in Task B bear different relations, in the case of each group, to the order prescribed in Task A. As in the previous experiment, the relations vary roughly from identity through a certain close similarity to a case of extreme difference. Each of the three types of relation is paired experimentally with each of the other two types.

In the case of the comparison of *identity* with *dissimilarity*, it was possible to substitute other specific orders while still holding constant the relations to be compared. Group ID–1 and Group ID–2 represent, therefore, a control to check upon the question of whether the relations (the similarity-relations between superordinate aspects) are responsible for the effects found by comparison or whether the specific orders chosen in Task B will account for the effects.

Experimental Series.—For Task A the arrangement of the experimental series was the same as that described in Experiment I. As before, the subjects learned the code by use of the prompting mechanism to the stage of producing three perfect trials in succession, requiring 20 trials on the average.

For Task B the subjects were given 40 trials, which brought them to a stage of learning in Code y beyond that reached in Code x. For each of the alternating serial orders 20 trials were provided so that there were 10 repetitions of each stimulus-number. To equate more perfectly the two serial orders with respect to possible differences in difficulty of the particular five-number combinations and with respect to the stages of learning, one half of the subjects of any group was started on the first trial with one of the orders while the other half was started with the other order.

An interval of one minute was allowed between trials in Task B (in contrast to the immediate succession of Task A) to allow time for the giving of the instructions and for the subject to adjust himself in readiness to follow the prescribed order. An interval of 15 minutes intervened between Tasks A and B. During this interval the subject was given instructions for Task B and preliminary training in the two serial orders to be used in alternation.

Instructions.—The instructions for Task A remained the same as in Experiment I. Important changes in instructions and procedure were, however, necessary for Task B. During the interval between the two tasks the subject was given practice in the two serial orders to be used by having him 'copy' letter-stimuli again, using now the two orders of Task B in alternation. The training was continued for each subject until he 'copied' according to the two orders with equal speed; the absolute amount of training varied somewhat from subject to subject. This preliminary training served to equate the two orders in regard to their newness and difficulty, and it assured equal speed of reaction at the start of the new task. It also gave the subject a chance to become adjusted to the alternation between two orders. After such training the chance of there being a tendency to make order-reversions seemed very slight.

In order that the likelihood of order-reversions might be even smaller, the subject was told in advance of each trial in Task B just which of the two orders was to be used next. In the interval between trials the experimenter displayed upon a card (suspended just above the exposure aperture) the announcement of the order to be used. The card remained exposed throughout the trial. In the interval following the ready signal, the subject reported verbally (before the stimulus appeared) the order which he was prepared to use.

Subjects.—Ten subjects served in each of the four groups. In the case of this experiment no preliminary equating of the groups was necessary since each subject served as his own control. As is later described, a separate control group of 20 subjects was used to establish norms for the paths of movement.

Results

Measurement of Code-Reversions.—Before the results based upon analysis of partial errors are discussed, the surprising infrequency of complete code-reversions (actual entrances into the critical slots appropriate to the previous code) deserves comment. For all 40 subjects the total number of such complete reversions was only 30, giving an average for each subject of only 0.8, which indicates reversions in fewer than 1 percent of the code-reactions. The results are, therefore, based primarily upon an analysis of partial reversion-errors (preliminary movements toward the critical reversion-slot) which were found to be present in large numbers.

The infrequency (almost complete absence, in fact) of complete reversion-errors in this experiment may be attributed to several factors. Several of the conditions of the experiment were such as to work against the appearance of complete reversions. The instructions directed the subject to strive for accuracy, and this emphasis made the subject alert to avoid committing actual errors by entering an incorrect slot; this emphasis would not prevent partial errors, since the subject did not know these would appear in the record. Moreover, during the first part of Task B the new code had to be learned by use of the prompting sector; during such a stage of learning very few errors are apt to occur with recourse to the prompting device available. Further training to greater speed might have produced more complete reversions.

The recorded movements in Task B were carefully analyzed for the four groups to determine the frequency of partial reversions. The general method of measuring deviations in movement and of establishing their 'significance' as reversion-errors by comparison with norms of usual variability has already been described in a previous publication.[16] The norms were established by a separate control group of 20 subjects.

The two codes were originally so chosen that in Task B the correct reaction-movement to any stimulus according to Code y would be clearly differentiable from a reaction-movement (reversion) correct according to Code x. The median degree of angular separation between the correct reaction slot and the reversion (critical) slot was 90° with the range from the minimum separation of 72° to the maximum of 135°. The lettered slots were so chosen and assigned that for each stimulus the reversion-movement was toward the center of the plate in relation to the correct movement. Partial reversion-errors were, then, in the nature of significant centripetal deviations from the direct path of movement to a given reaction-slot.

In establishing the nature of 'normal' movements to a given reaction-slot, the limits of normal variation from the direct path to the reaction-slot were measured in angular units in the centripetal direction. The 90th percentile deviation-value was taken to represent the limit of deviation under normal conditions. The norm for each reaction-slot was based upon 400 separate reactions (20 reactions from each of the 20 control subjects). The procedure for the control group was precisely that for the experimental groups in Task B except for the fact that the 34521 serial order of substitution was used throughout.

The norms calculated in the above manner for the 10 different reaction-slots used in Task B were as follows: A 38.9°, C 31.3°, F 25.9°, H 20.2°, K 7.3°, M 14.4°, O 21.5°, R 26.3°, T 32.4°, U 37.1°. (The large variation in these norms is a function of the distance of the reaction-slot from the center of the reaction-plate, as is shown by the fact that the amount of deviation increased progressively as the distance of the reaction-slot from the center of the plate, reaction-slot K, increased.) In view of the tremendous amount of labor involved in the analysis of the records of

[16] Siipola, *op. cit.*, p. 61 ff.

400 movement-paths for each reaction-slot, only a determination of the status of each reaction as either 'normal' or 'significant' was attempted in this experiment. Reactions in Task B were regarded as significantly influenced by reversion when they deviated in the reversion-direction beyond the limits established by the above norms.

The results, then, are treated in terms of the frequency of significant deviations in the direction toward the reversion-movement, that is, in terms of complete and partial reversion errors. A summary of these results is presented in Table 7. Since the total number of critically distorted movements possible for any one subject was 100 for each of the two serial orders, these figures in Table 7 can be read as percentages. The results for Group ID represent the combined results of Group ID–1 and Group ID–2.

TABLE 7

FREQUENCY OF CODE-REVERSIONS

	Mean No. Reversions		S.D.	$S.D._M$	Critical Ratios
Group ID (20)	Trials I	38.6	18.8	4.3	Trials I, Trials D = 6.8
	Trials D	20.9	13.7	3.2	
Group SD (10)	Trials S	33.8	18.5	6.5	Trials S, Trials D = 3.8
	Trials D	20.8	13.9	5.2	
Group IS (10)	Trials I	35.4	15.2	5.4	Trials I, Trials S = 2.4
	Trials S	29.2	11.6	4.1	

The results in Table 7 show that, although the change in code was constant in every case, the frequency of code-reversions did not remain constant, but was instead definitely influenced by the complicating factor of superordinate similarity. That the nature of the inter-task relation at the superordinate level, the degree of similarity in serial order, had a pronounced and consistent effect upon the frequency of return to previously learned code-reactions is shown by a general comparison including all of the means. The largest number of code-reversions (35 percent and 39 percent) occurred in the trials in which the serial orders in the two tasks were identical; the next largest (29 percent and 34 percent) in the trials in which the serial orders were similar; and the smallest number (21 percent) in the trials in which the serial orders were widely dissimilar.

Separate comparisons within the groups are more reliable than such a general comparison as the above, since within any single group the possible influence of such extraneous variables as stage of learning is held constant for the two serial orders to be compared. Such intra-group comparisons result in complete agreement with the more general findings to the effect that the influence of superordinate similarity upon subordinate code-reversions is greatest in the case of

identity, next greatest in the case of similar serial orders, and smallest in the case of dissimilar serial orders. A direct relationship between superordinate similarity and subordinate code-reversions is therefore revealed; the greater the similarity between the serial orders of the two tasks, the greater the tendency for code-reversions.

The reliability of these results is indicated by the consistency of the relations in all three of the intra-group comparisons. More evidence for the reliability of the trends is afforded by analysis of the individual results. Of the 40 subjects, only 4 showed direct disagreement with the findings from the group results and only 4 additional subjects show equality of reversion-effects for the two orders compared. Statistical determination of the reliabilities of the group figures (see critical ratios in Table 7), although questionable in value since the number of cases is small, indicates that the differences between trials I and D and between trials S and D are clearly reliable while the difference between trials I and S is fairly reliable.[17]

The high degree of variability indicated by the standard deviations has very little bearing upon the validity of the conclusions, which are based upon comparisons of relative frequencies for the two serial orders concerned and not upon the absolute number of reversions found. The large variability-figures are readily understandable in the light of the relation between the number of trials occupied by prompted, initial learning of the new code and the number of trials remaining for the use of the code. It was only after the first stage of reliance upon the prompting device had been passed that the reversion errors ordinarily occurred. If a subject, then, spent a large number of the 40 trials reacting slowly with the aid of prompting, he automatically reduced the opportunity for reversion as compared to that of a subject who gave up the prompting device very early and performed the majority of the 40 trials with reliance upon his own skill. Subjects varied greatly in the manner in which they distributed the available trials between prompted learning and self-reliant performance, so that the absolute numbers of reversions vary greatly with the opportunity provided from subject to subject. Since the comparisons between serial orders are based upon alternate trials of the same subjects (learning the same code for both orders), the variability from subject to subject cannot influence the relative frequencies of reversions for the two orders.

Since the stage of proficiency in Task B was so closely related to the number of reversions made at any given time, a high degree of correlation between the numbers of reversions made in even and odd trials of a given experimental series (the trials of the two alternating orders) should be expected. Correlation of the mean number of reversions of the two alternating serial orders gave the following coefficients: Group ID, + .81; Group SD, + .85; Group IS, + .89. Another factor in addition to comparability of stage of learning is partly accountable for these high correlations, namely serial effects from one trial to the next in the series. Despite the separation of trials by an interval during which an instruction was given, there was clearly a tendency for a reversion in one trial to be followed by a reversion in the trial immediately following. Moreover, characteristics of particular subjects, such as general rapidity or freedom in movement and high susceptibility to confusion, would also tend to show up equally in both orders and hence give high correlation. The high correlation-figures obtained support the choice of the technique based upon alternation and comparison within groups.

The differences found between the two alternating serial orders of Task B have been interpreted in terms of their similarity-relation-

[17] In the calculation of the standard error of the means the small number of cases was compensated for by using N–1 for Group ID and N–2 for Groups SD and ID instead of N. In the calculation of the standard error of the differences the degree of correlation between alternate trials of each group was taken into account.

ship to the order learned in Task A. It might still be maintained that the differences were dependent upon the inherent nature or difficulty of the particular orders used in Task B rather than upon the similarity-relationships of these orders to that of Task A. This point can be decided by an experiment in which the same similarity-relations are compared by the use of different specific serial orders.

Group ID–2 in comparison to Group ID–1 represents such a check-experiment (described in Table 6). For these two groups the two serial orders of Task B were the same (34521 and numerical orders), but in the case of Group ID–1 the 34521-order was learned in Task A while for Group ID–2 the order of numerical value was learned in Task A. Each of the orders of Task B was thus identical in the one case and dissimilar in the other case with respect to the previously learned order; the same similarity-relationship was borne in the two cases by different specific orders. If the interpretation in terms of similarity-relationship between tasks is correct, then the direction of the differences between the particular serial orders should be reversed between the two groups. If the differences are dependent merely upon the particular orders used, then the direction of the differences should remain the same in both groups.

TABLE 8

FREQUENCY OF CODE-REVERSIONS IN SUB-GROUPS ID–1 AND ID–2

	34521-Order Mean No. Reversions	Order of Numerical Value Mean No. Reversions
Group ID–1	41.0 (Identical Order)	24.2 (Dissimilar Order)
Group ID–2	17.6 (Dissimilar Order)	36.2 (Identical Order)

The results for Groups ID–1 and ID–2 are given in Table 8. The larger number of reversions is found in both groups for the order in Task B which is identical to the order of Task A. The differences in frequency of reversion seem, then, related to the different inter-task relations in serial order rather than being dependent upon any particular serial orders.

Measurements of Reaction-Time.—The influences of code-reversions upon reaction-time are shown in Table 9. These results agree strikingly with the above findings upon code-reversion and add support to the conclusions already reached. The longest times (24.3 and 23.5 sec.) occurred for the trials in which the serial orders in the two tasks were identical; the next longest (23.2 and 22.9 sec.) when the two orders were similar, and the shortest times (22.2 and 21.2 sec.) when the serial orders were dissimilar.

TABLE 9

MEAN REACTION-TIMES IN TASK B (20 ALTERNATE TRIALS)

	Mean Reaction-Time in secs.		S.D.	$S.D._M$	Critical Ratios
Group ID (20)	Trials I	24.3	4.62	1.06	Trials I, Trials D = 3.9
	Trials D	22.2	3.62	.83	
Group SD (10)	Trials S	23.2	2.56	.90	Trials S, Trials D = 2.8
	Trials D	21.2	2.68	.94	
Group IS (10)	Trials I	23.5	4.14	1.46	Trials I, Trials S = 0.9
	Trials S	22.9	3.06	1.08	

The time-results do not show as reliable differences as did the data upon reversions. Reliability is indicated, however, by the consistency of the results and by the relatively small number of individual exceptions to the general trends (in all 9 exceptions among 40 subjects). Statistical determination of reliability is again of questionable value in view of the small number of cases; calculation of critical ratios (see Table 9) would indicate that the differences in the cases of both Group ID and Group SD are reliable whereas the difference in the case of Group IS is of questionable reliability.

Again the variability of the individual averages is high, and this fact is undoubtedly to be interpreted as due to the same influences as have been previously discussed. Also, as might be expected, the mean reaction-times for the two orders of Task B show a high degree of correlation: for Group ID + .87; for Group SD + .69; for Group IS + .90.

The fact that the results in reaction-time agree perfectly with the results in terms of reversions is not surprising. In the case of this experiment the conditions were such as to force agreement between the two measures. Practically all extraneous factors which might ordinarily have been reflected in the times were here eliminated or controlled. Preliminary training in use of the serial orders eliminated possible effects of such factors as novelty of the tasks and confusion between the serial orders. The alternation of the orders for the same subjects controlled (equated) such factors as the stage of learning reached and individual differences in speed and freedom of movement. Moreover, the conditions were such as to induce partial (rather than complete) reversion-errors, and such partial errors characteristically involve long reaction-times.[18] It should be remembered, however, that the measurements of reaction-time alone provide no means of clearly identifying the phenomena responsible for the time-effects. Hence, it would be impossible to establish the significance of the reaction-time scores without the information supplied in the more direct evidence obtained by the other method of measurement in terms of reversion-movements themselves.

From the results of this experiment it may, then, be concluded that similarity in a superordinate aspect of the task has a definite and a consistent effect upon reversion-phenomena of the subordinate type. Subordinate code-reversion phenomena (as measured either by frequency of code-reversions or by the effect of such reversions upon reaction-time) vary directly with the degree of similarity in the superordinate aspect of the task; the greater the degree of super-

[18] *Op. cit.*, p. 69 ff.

ordinate similarity the more frequent the code-reversions and the longer the reaction-time. This finding has considerable theoretical significance and provides a clue to an understanding of the previous results. After a brief theoretical discussion, a comparison of the present results with those of the previous two experiments will be made.

To find that superordinate aspects of activity do exert an influence upon performance at subordinate levels is not surprising. All of the present theories of learning recognize the influence of such superordinate aspects as primary drives or needs upon the learning of subordinate acts or items of performance; the rules governing the operation of such influences are to be found in the various versions of the 'law of effect.' The present investigation, however, has been concerned with the influence of superordinate aspects which belong to an intermediate level—aspects which are superordinate to the separate response-items but still do not constitute primary drives or needs. The influence of such superordinate aspects—tasks, methods, attitudes—upon subordinate items is also well recognized although it has received only minor consideration in systematic and experimental treatments of learning. In so far as the specific problem of this experiment is concerned, none of the present learning theories makes explicit the statement of the exact relationship to be expected between superordinate similarity and transfer in the subordinate aspects.

There is throughout the theoretical literature a hint that the relation between similarity in superordinate aspects and subordinate transfer may be a direct one. For example, both Lewin and Bartlett imply that similarity between the attitudes, tasks, and sets in the original and new activity plays the dominant role in the determination of transfer.[19] For Hull also, identity of drives and anticipatory reactions plays an important part in producing transfer. Hull has, for example, made the deduction that "other things being equal, transfer should be distinctly more effective where the same drive (*e.g.* hunger) is involved in both the old and new situations." [20] Tolman avoids the problem of similarity, but he emphasizes the disruptive influence upon learning of changes in both superordinate and subordinate drives and goals.[21]

No previous direct experimental evidence is available upon the particular relationship considered in the present experiment. There is available, however, indirect evidence from the results of experiments in transfer, learning proper, and retroactive inhibition. This indirect evidence tends to support the finding of the present experiment for a direct relation between similarity in superordinate aspects and subordinate transfer.

In the field of transfer, the experiments of Schwarz are most pertinent to the specific problem concerned. Schwarz, who has studied exhaustively the influence of the structure of an activity upon reversion tendency, found that the frequency of reversion to a previously learned subordinate act decreases when the structure of the second task becomes dissimilar to that of the original

[19] LEWIN, K., Das Problem der Willensmessung und der Assoziation, *Psychol. Forsch.*, 1922, 1, 191–302 and 2, 65–140; BARTLETT, F. C., *Remembering.* A study in experimental and social psychology. New York: Macmillan, 1932, pp. 191 ff., 206 ff.

[20] HULL, C. L., The concept of the habit-family hierarchy and maze learning, *Psychol. Rev.*, 1934, 41, 33–52, 134–152. (See especially p. 45.)

[21] TOLMAN, E. C., *Purposive behavior in animals and men*, New York: Century, 1932, pp. 39 ff., 71 ff., 187 ff.

activity.[22] Lewin has also shown that if two successive tasks are identical (*e.g.*, reproduction), subordinate reversions are frequent, whereas such reversions are rare if the second task is dissimilar (*e.g.*, rhyming instead of reproduction).[23]

In the field of retroactive inhibition the following two researches tend to support our findings. Gibson and Gibson found that identity in task (learning paired-items) between original and interpolated activities produced more decrement than did a difference in task (cancellation in contrast to learning paired items).[24] Waters and Peel found that identity in the method of learning (serial learning) between original and interpolated tasks produced more decrement than did a difference in method of learning (paired-associates in contrast to serial learning).[25]

Even in the field of learning proper, it is generally accepted that identity in such superordinate aspects as drive, goal, or task favors 'transfer' of subordinate acts from trial to trial, whereas dissimilarity in superordinate aspects reduces such transfer. The numerous experiments on disruption in the field of animal learning, which involve a change in the nature of the drive or goal, are relevant here. It is also generally accepted that the processes of recall and recognition are favored if such aspects as the task, method, and set at the time of recall are identical or similar to those present during the original learning process. For example, Zangwill has found that by changing the set of the subject, one can produce non-recognition of previously exposed items.[26]

From the direct evidence of the present experiment and the indirect evidence of other investigations it appears, then, that the degree of similarity in such superordinate aspects of activity as the task and method functioning during the learning of specific stimulus-response items, is an important determinant of the occurrence of these subordinate responses at a later occasion. The broad rule suggested is that the greater the degree of superordinate similarity, the greater will be the tendency for subordinate transfer proper.

The fact that the degree of similarity in superordinate aspects of habits produces consistent and measurable effects upon subordinate reversion is strong evidence for the conclusion that habits, some habits at least, consist of functionally interrelated (rather than independent) aspects, and that such habits may properly be referred to as habit-systems or habit-structures. In so far as such functional interaction between different aspects or levels is present, the study and prediction of inter-habit phenomena must become a highly complicated task. An adequate experimental program will have to include direct investigation of these complex interactive effects which occur when variations in more than one aspect or level are involved; experimentation which limits itself to variation within a single level will not yield complete knowledge of the phenomena involved.

[22] Schwarz, G., Über Rückfälligkeit bei Umgewöhnung, *Psychol. Forsch.*, 1927, **9**, 86–158; 1933, **18**, 143–190.

[23] Lewin, K., *op. cit.*

[24] Gibson, E. J. & Gibson, J. J., Retention and the interpolated task, *Amer. J. Psychol.*, 1934, **46**, 603–610.

[25] Waters, R. H. & Peel, Z. E., Similarity in the form of original and interpolated learning and retroactive inhibition, *Amer. J. Psychol.*, 1935, **47**, 477–481.

[26] Zangwill, P. L., A study of the significance of set in recognition, *Brit. J. Psychol.*, 1937, **28**, 12–17.

Summary and Comparison of Results

Comparison of Measures of Reaction-Time (Transfer-Effects).—The reaction-time results of the three closely related experiments presented may be compared most readily by plotting them together in a single figure, as is done in Fig. 1. In order to make comparison easier, the reaction-time results for Group I were considered as a norm in each experiment, and the ratio of the reaction-time of each group to the reaction-time of Group I was obtained. These ratios given in Fig. 1 are all based upon the average reaction-time per trial (40 trials) in Task B. In the case of each of the curves obtained, the relative position of the three groups, representing three different degrees of superordinate similarity, is the main feature of interest here.

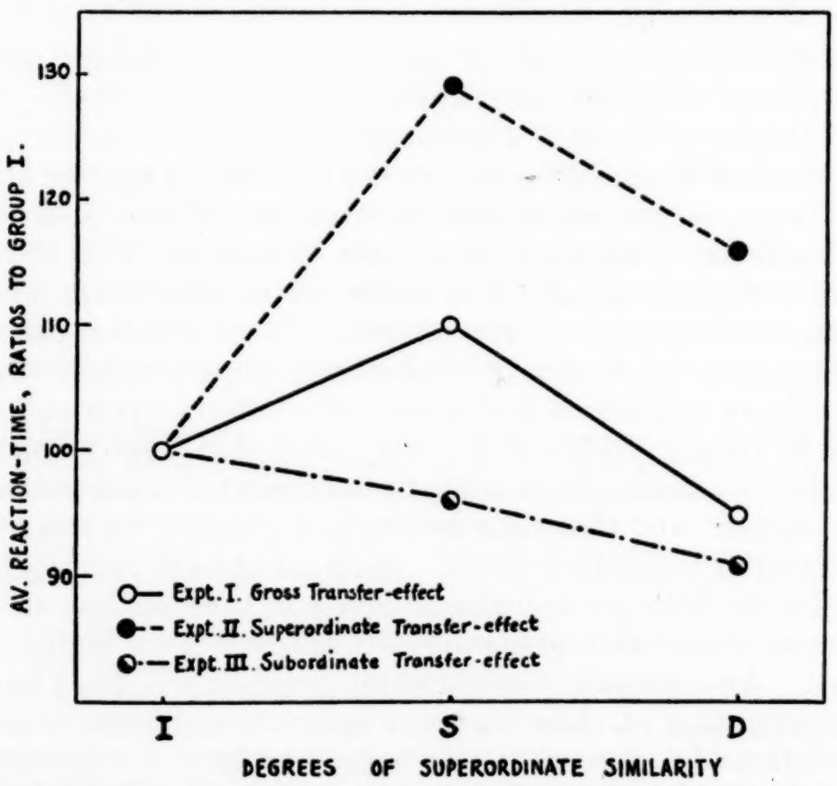

Fig. 1. Summary graph based upon average reaction-times for 40 trials in Task B. The values plotted represent the ratio of the average reaction-time of each of the 3 groups (representing 3 degrees of similarity) to the average reaction-time of Group I.

It is at once apparent from Fig. 1 that the curious results obtained in Experiment I on gross transfer do not correspond to the results obtained either in Experiment II on superordinate transfer-effect or in Experiment III on subordinate transfer-effect. The relative order of the three groups in respect to efficiency in Task B (from lowest to highest) was S, I, D in Experiment I, whereas it was S, D, I in Experiment II and I, S, D in Experiment III.

Assuming that variation in superordinate similarity would affect reversion-phenomena at only the same superordinate level, one might have expected that one could predict the gross transfer curve for Experiment I from the curve of Experiment II. Such prediction would have indicated maximal efficiency for Group I rather than for Group D, for which it was actually found. This discrepancy between the curves of Experiments I and II suggested the possibility that variation of superordinate similarity may also affect reversion-phenomena at a subordinate level. The curve representing the operation of such an influence in isolation (Experiment III) is of the precise type needed to account for the discrepancy between the other two curves and for the previously inexplicable position of Group D in Experiment I. The gross transfer results in Experiment I seem, then, to represent some combination of the influences at both the superordinate and subordinate levels. The manner in which the two types of transfer-effect combine to give the gross transfer curve (see Fig. 1) indicates that the combined effect is not a simple additive function of the two variables; nor do the two variables seem to be of equal weight. Rather, the gross transfer-effects measured represent a complex product of the inter-task influences at both the superordinate and subordinate level.

The chief value of the above interpretation of the gross transfer results lies in the fact that it renders understandable an otherwise puzzling result by reference to the operation of factors upon which experimental data have been provided. The fact that, with subordinate (code) conditions held constant, the change to a widely dissimilar serial order produced more positive transfer-effect than did continuation with the identical serial order was impossible to understand in terms of the common conceptions of transfer. In terms of the two types of reversion-phenomena and their different functional relations to the variable of superordinate similarity, the previous finding becomes not only understandable but also predictable.

In so far as the prediction of *transfer-effects* in relation to superordinate similarity is concerned, the following broad rule is suggested by the curves in Fig. 1: The relation between similarity in a superordinate aspect of the task and *transfer-effect* will vary in dependence upon the kind or level of the reversion-phenomena reflected in the measurement of the transfer-effects.

a. If the measurement reflects only reversion-phenomena of the same level at which the variation in similarity is produced, the familiar interference curve of Robinson will be obtained. The particular shape of the curve has been shown to be related to a shift in the criterion of transfer in the region of identity. (Proof—Experiment II.)

b. If the measurement reflects only reversion-phenomena at a different and lower level than that in which the variation in similarity is produced, the relation between superordinate similarity and transfer-effect will be a direct one. (Proof—Experiment III.)

c. If the measurement reflects more than one level of reversion-phenomena, the composite curve will represent a complex product of the separate curves for the various levels of reversion involved. In this case, special rules to cover the manner in which effects at different levels combine will have to be devised. (Proof—Experiment I.)

Comparison of Measures of Reversion (Transfer-Proper).—In so far as the prediction of *transfer proper* (reversion) in relation to superordinate similarity is concerned, the following simple rule is suggested by the results of Experiments II and III: The relation between similarity in a superordinate aspect of the task and reversion-tendency is in general a direct one; the frequency of reversions will increase directly with the degree of superordinate similarity regardless of the level of measurement.

a. Complete consistency of this rule is contingent upon the correctness of the interpretation previously given for the case in which reversion is measured at the same level at which the variation in similarity is produced. Under these conditions reversions cannot be distinguished from correct responses in the region of identity. If the 'correct reversions' are scored as 'real' reversions, this case of identity falls into line with the trend for a direct relation between superordinate similarity and transfer proper. (Proof—Experiment II.)

b. When reversion is measured at levels subordinate to the level at which the variation in similarity is produced, the relation between superordinate similarity and reversion-tendency is clearly a direct one. (Proof—Experiment III.)

Even if the relationship between reversion and similarity should be as simple and direct as that prescribed by the above hypothesis, the prediction of reversion for a given inter-task relationship would still remain a complicated problem. First, it would be necessary always to identify the different aspects or levels of the habit-systems concerned and to state precisely in these terms the relationships between the two tasks. In order to predict reversion at any given level it would then be necessary to take into account the similarity-relations at all levels superordinate to the level of measurement as well as at the level at which measurement is made.

The present experiments have raised rather than solved questions dealing with the complex structure of habit-systems, relations between superordinate and subordinate aspects of such systems, and the functional interrelations of differently structured systems. Throughout, only a certain type of superordinate-subordinate relation has

been investigated. Whether all superordinate aspects of activity (primary drives, secondary drives, methods of procedure, sets) bear the same relation to subordinate aspects of activity is a serious question which can only be answered by further experimentation. Perhaps the most significant suggestion of the present research is that of the necessity for defining activities or habit-systems in terms of precise variables. For this purpose there are at present almost no concepts or terms available, and experimental methods for transfer have been limited primarily to those dealing with a single aspect of activity, usually a subordinate aspect. The need for appropriate concepts and experimental methods in this field is particularly urgent at this time in view of the present trend toward integration of simple phenomena such as code-reversion with the most complex phenomena such as regression at the final, superordinate level of personality structures.

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CARDIAC STARTLE IN MAN

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This paper [1] deals with changes in heart rate induced in man by pistol shots. In a first and principal section it defines a simple *index* of *cardiac startle* which can be used not only for the study of cardiac startle in relation to eliciting conditions and in relation to other concomitant responses, but also for specification of individual differences. A second section involves the application of the measure to the study of the relation of cardiac startle to stimulus, to concomitant breathing responses, and to subjective report.

The Measurement of Cardiac Startle.—The increase in heart rate following a startle stimulus over its level at the time of stimulation or just prior to stimulation has been a very usual measure of the response. The adequacy of this measure is based on the assumption that the pre-stimulus level is constant. As far back as 1882, however, Fredericq (**3**, 81, 86) wrote: "On sait depuis longtemps que la fréquence des pulsations cardiaques n'est pas toujours la même aux deux temps de la respiration." He proceeded then to demonstrate experimentally that "sur des Chiens à poitrine ouverte, . . . cette activité rhythmée du centre d'arrêt du coeur, qui ralentit les battements à chaque expiration, est de nature automatique et non réflexe."

Fredericq (**3**, 81) believed that "chez l'Homme et chez le Lapin cette influence est peu marquée." Beebe-Center and Stevens, however, have shown that co-variation of heart rate with breathing phase may influence markedly the increment of heart rate elicited by startle stimuli in man if the response is measured from the last beat before the stimulus to the beat constituting the first peak of heart rate after the stimulus. Their figure is reproduced here as Fig. 1. It shows, for one subject, increment of heart rate and action time of stimulus (time between stimulus and peak of heart rate) for twenty-one shots fired at full inspiration and twenty-one shots fired at full expiration. The letters I and E represent the medians for these two sets of shots.

It is doubtful, then, that the usual measure of cardiac startle is adequate. The first part of the present investigation is a further study of the relation between the increment of heart rate elicited by a startle stimulus and the cyclical changes in heart rate correlated with breathing. It seeks to discover a measure of cardiac startle

[1] The authors are indebted to S. S. Stevens for considerable advice and technical assistance.

which will be independent of breathing phase, and thus truly representative of the response.

In a first series of experiments, two groups of ten subjects each were used; the first ten were stimulated at the moment of inspiration, the second at that of expiration. Breathing was registered by a

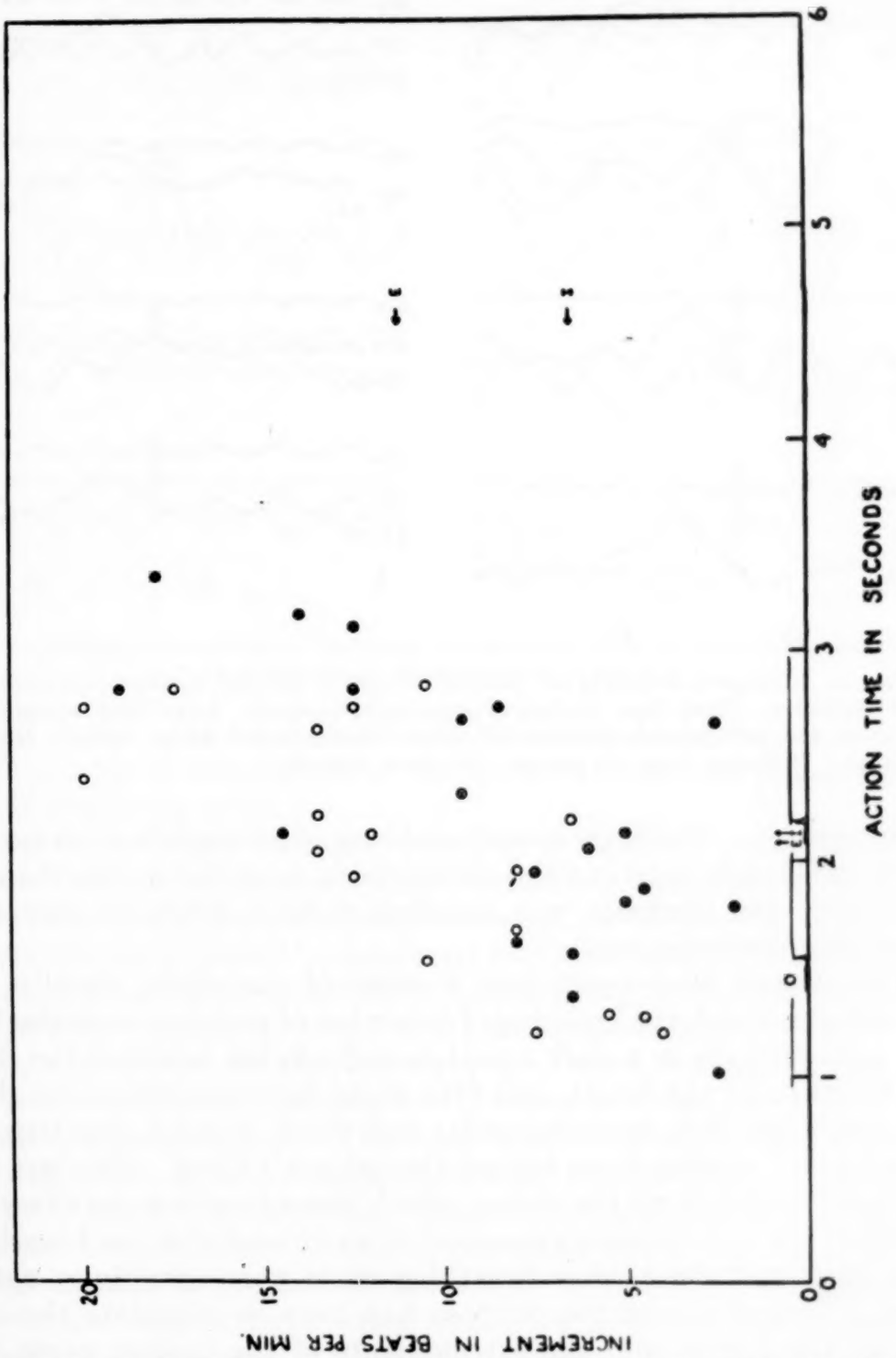

FIG. 1. Influence of position of stimulus in breathing cycle on cardiac acceleration elicited by shot. I and E represent medians for shots fired at full inspiration and expiration respectively.

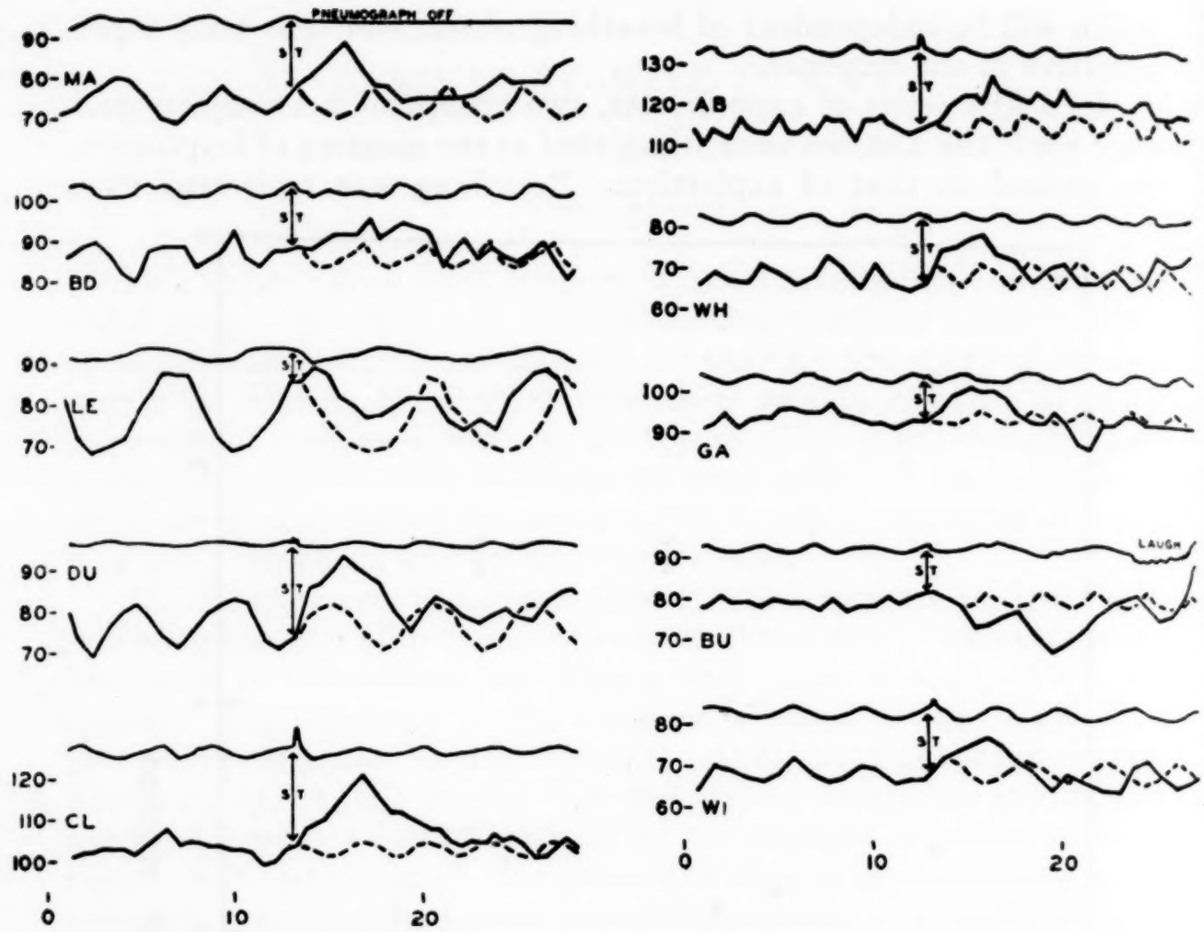

FIG. 2*a*. Changes in breathing and heart-rate elicited by first shot for 10 subjects stimulated at full inspiration. Upper lines: tracings of pneumograph records. Lower lines: actual heart-rate (solid) and extrapolated heart-rate (broken). Double ended arrows indicate times of stimulation. Ordinates: beats per minute. Abscissae: seconds.

pneumograph. The heart record made use of an amplification system which sufficiently enlarged the difference in potential across the subject's body (an electrode was attached to each wrist) to operate a simple electro-cardiograph.

The stimuli used were: first, a series of gun shots, usually five in number; second, the brushing of a number of strings across the face (the subjects were in a dark room), usually twice, between the third and fourth, and the fourth and fifth shots (but sometimes the shots and brushings were interchanged); and third, a noise simulating a calf's "moo" coming from behind the subject's head. The last was used until replaced by the string, which proved to be more effective.

When the records were examined, it was found that the breathing cycle itself and the cardiac breathing cycle were sometimes out of phase. Thus although the purpose had been to stimulate the subjects at the fastest and slowest moments of the cardiac cycle, the preponderance of subjects had actually been stimulated near the

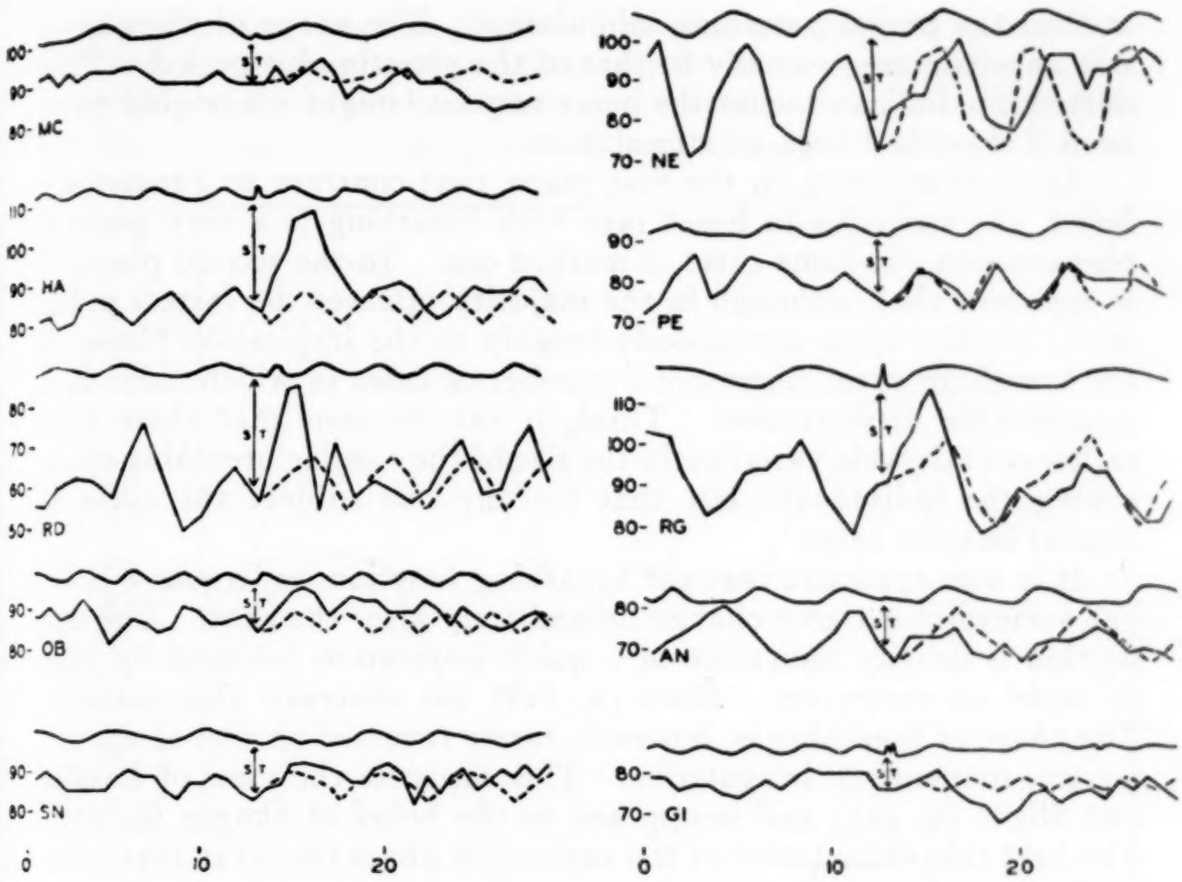

FIG. 2*b*. Changes in breathing and heart-rate elicited by first shots for 10 subjects stimulated at full expiration. Conventions as in fig. 2*a*.

slowest point. Six further subjects were introduced to give a more ample sample of stimulation at the fastest and slowest phases of the cardiac breathing cycle.

Sixteen subjects, including six each of the two groups of eight subjects stimulated respectively at the fastest and slowest points of the cardiac breathing cycle, returned after an interval of two weeks to a month for a 'repeat' experiment which consisted of a single shot for ten of the subjects and a series of five shots for six of them under circumstances similar to those of the first experiment.

Figures 2*a* and 2*b* give the data for twelve seconds before and eighteen seconds after stimulation for the first shot in each of the twenty original subjects. The lower solid lines represent the actual response. The dotted line represents an hypothetical continuation of the cardiac breathing cycle. This was obtained by averaging the peak and trough values of the cardiac cycle due to breathing in the twelve seconds before stimulation, and the resultant average peak value and average trough value were plotted in the fifteen seconds following the stimulus at a distance from each other on the abscissae equivalent to the average of the distance by which they were separ-

ated in the period preceding stimulation. The shape of the curves was approximated visually to that of the pre-stimulus period. This dotted line indicates what the heart response might reasonably have been if there had been no stimulation.

Inspection shows, in the first place, that contrary to Fredericq's belief, the variation in heart rate with breathing is a very general phenomenon—in some cases, a marked one. In the second place, it is apparent that, although in the majority of cases the fastest point in the cardiac cycle corresponds roughly to the inspiration phase of the breathing cycle, there are a number of cases in which there is a considerable displacement. Third, it can be seen that there is a rather considerable variation in the size of the cardiac breathing cycle among the individuals, but that for any one subject the cycle is regular in most cases.

It is also apparent that the breathing function undergoes a brief but somewhat extreme change immediately after the shot. The deflection is usually indicative of a quick inspiration followed by just as rapid an expiration. Blatz (**2**, 128) has observed this pattern. The phase of breathing is, however, rarely reversed or altered except for this momentary irregularity. This supports the view of Landis and Slight (**5**, 417) and is opposed to the belief of Skaggs (**9**, 310) who held that stimulation at the expiratory phase results in reversion to the inspiratory phase.

Inasmuch as the phase relations were not constant (*i.e.*, the slowest point in the cardiac cycle did not come invariably at the point of expiration), it seemed advisable to regroup the data according to the point of the cardiac cycle at which stimulation took place. Five additional subjects were introduced at this time to give eight subjects stimulated at the slowest phase of the cardiac cycle and an equal number stimulated at the fastest phase.

The fact that variation in heart rate with breathing is the rule, makes it unlikely that the simple procedure of measuring startle by the action peak (highest peak within five seconds after the stimulus) minus the level at the time of stimulation is reliable. That this measure varies with the point of stimulation is clear from Fig. 3, which represents for each second after the stimulus the total increment of rate above the stimulus level elicited by the first shot for each of the two groups of eight subjects.

A rather obvious hypothesis to account for this difference is that the response is a summative one; *i.e.*, that it is due to two influences: the startle response itself, and the concomitant functioning of the mechanism causing the cardiac variations with breathing. If the response were a simple summation of these two influences, then the increment in rate should be less when the influences were out of phase

than when they were in phase. The simplest manner in which to test this hypothesis was to extrapolate for each observer the cardiac breathing cycle beyond the moment of stimulation, as indicated by the dotted lines on Figs. 2*a* and 2*b*, and to measure for each second

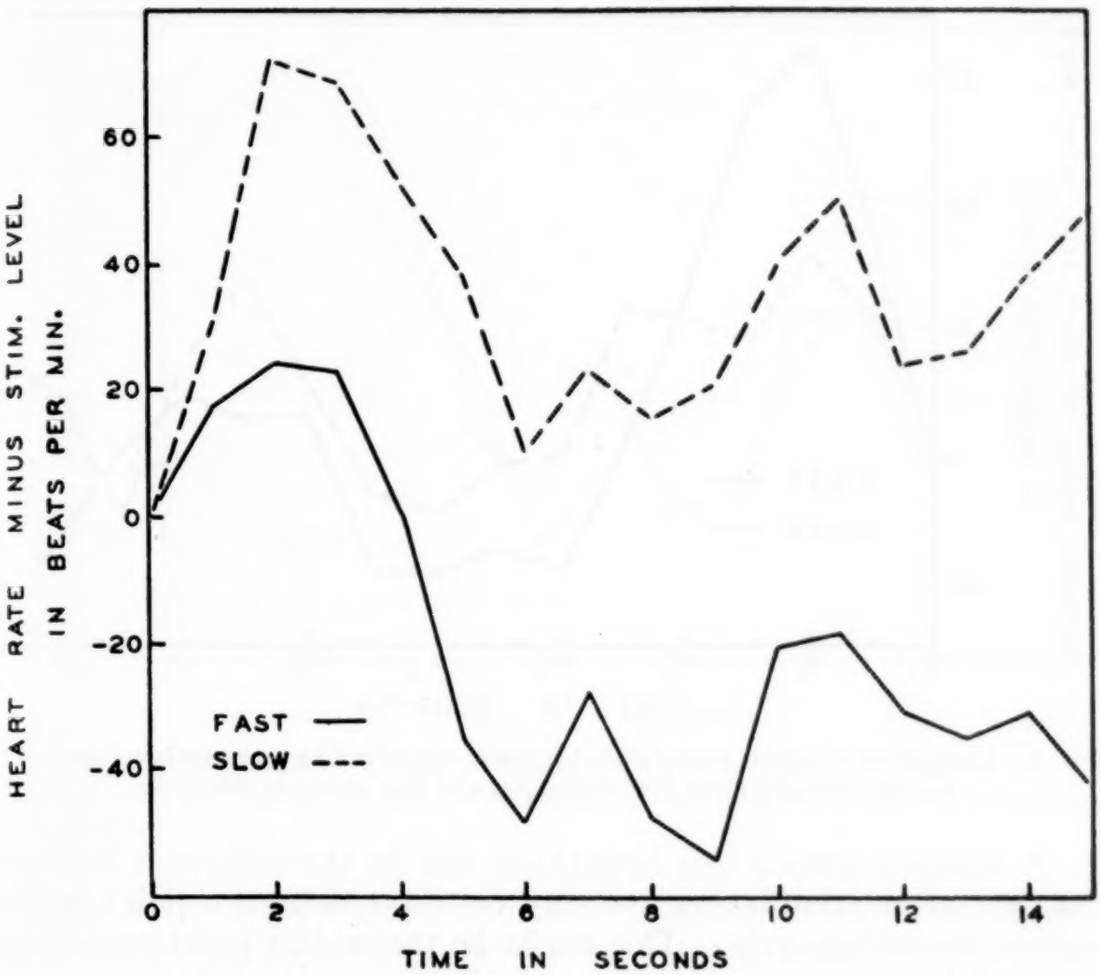

FIG. 3. Comparison of cardiac acceleration, relative to rate at time of stimulation, for shots fired during fast and slow phases of respiratory cardiac cycle.

after the stimulus the difference between the actual rate and the rate indicated by extrapolation.

According to the hypothesis of summation, the combined differences between the expected and actual rates for successive seconds after the stimulus should be the same for the eight cases stimulated at inspiration as for the eight stimulated at expiration. Figure 4 shows the reaction of the two groups using this measure for the fifteen seconds after stimulation. It can be seen, particularly in the first six seconds, that the patterns are sufficiently different to discredit the hypothesis of summation.

The alternate hypothesis suggested is that the startle response is in the nature of a replacement phenomenon: that the startle response,

instead of summating with the cardiac breathing cycle, simply supersedes it. According to this view the heart rate will increase to approximately the same point whether the stimulus is presented at a fast or slow point in the cardiac breathing cycle.

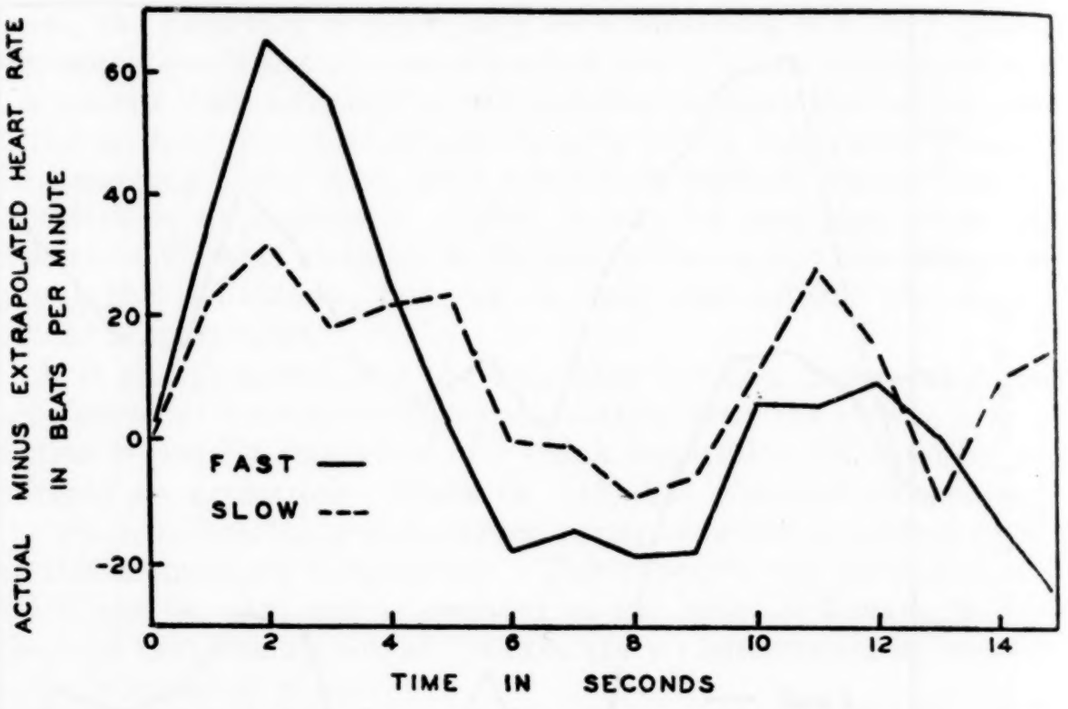

FIG. 4. Comparison of cardiac acceleration, relative to rate according to extrapolated respiratory cardiac cycle, for shots fired during fast and slow phases of this cycle.

A measure testing this hypothesis can be the difference between the rate after stimulation and any constant reference point in the cardiac breathing cycle. This might be the middle point or average value of the heart rate preceding the stimulus, or it might be an average of preceding troughs or peaks. The latter type of measure was chosen, quite arbitrarily. The average of the peak values in the twelve seconds preceding stimulation was determined for each individual. The total difference for each group of eight observers between this 'peak' value and the actual response value at each second for fifteen seconds following the stimulus is indicated in Fig. 5. For subjects stimulated during a slow phase a greater initial change in heart rate is necessary in order to reach the level corresponding to cardiac startle, but otherwise the responses are similar. This indicates that the response is independent of the point in the cardiac breathing cycle at which stimulation occurs—that the response is a replacement reaction.

These results, however, are only indications. The original samples were small. To get further evidence, it was thought best to

carry out a 'repeat' experiment with a number of the subjects. Instead of having to depend on the statistical equality of the total responses of two groups of subjects stimulated at the fastest and slowest points of the cardiac breathing cycle, it was now possible to

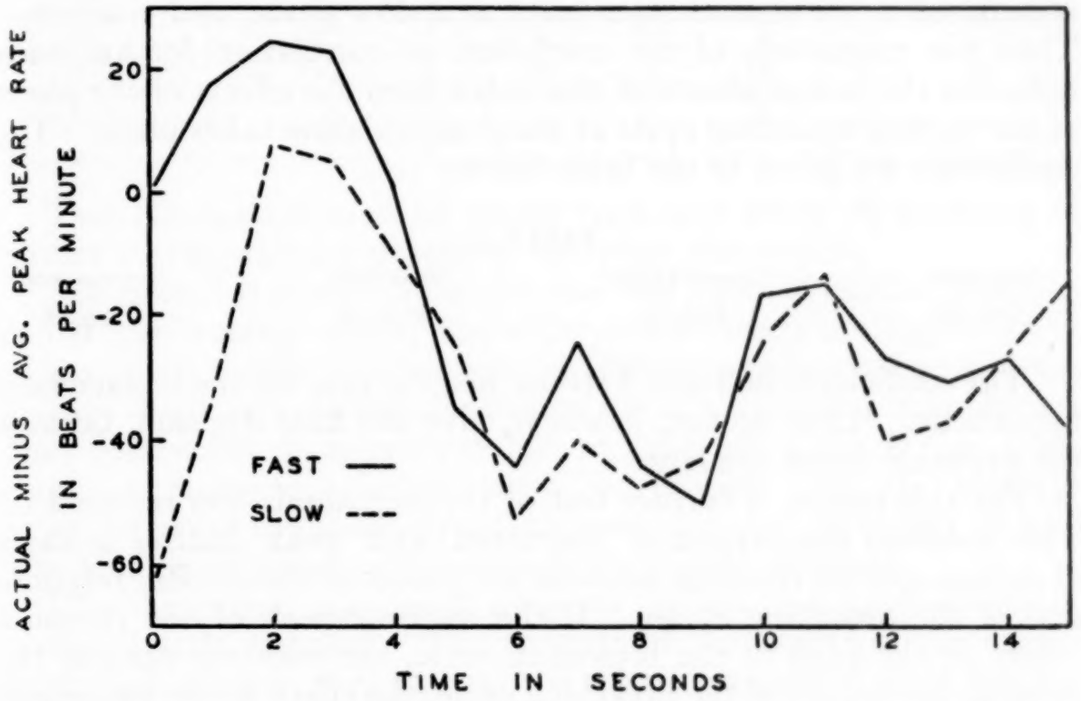

FIG. 5. Comparison of cardiac acceleration, relative to average of peaks of respiratory cardiac cycle during 12 seconds before stimulation, for shots fired during fast and slow phases of this cycle.

compare the responses for the same individual when stimulated at the two distinct phases of the cycle. (It was assumed that because of the lapse of time, the second experiment would be approximately as effective as the first in producing startle.)

In order to save time in the analysis of data, the responses were measured only at one point, hereafter called the *response-peak*, and defined as the highest peak of heart rate in the first five seconds after stimulation. Four indices of response were used: the '*raw index*,' defined as the difference between the response peak and the rate at time of stimulation; the '*corrected index*,' defined as the difference between the response-peak and the rate corresponding to a point of the breathing cycle just one cycle earlier than the response-peak; the '*peak index*,' defined as the difference between the response-peak and the average of the peak rates during the twelve seconds preceding stimulation; and the '*average index*,' defined as the difference between the response-peak and the average heart rate for twelve seconds before stimulation.

In the case of each of these four indices, the coefficient of correlation was determined between the responses of sixteen observers to the first shot of the first session and their responses to the first shot of a second session. The eight observers who had been stimulated in the first session at a fast phase of the cardiac breathing cycle were stimulated in the second experiment at a slow phase, and vice versa. Thus the magnitude of the coefficient of correlation for an index indicates the independence of this index from the effects of the phase of the cardiac breathing cycle at which stimulation takes place. The coefficients are given in the table below:

TABLE I

'Raw index'	'Corrected index'	'Peak index'	'Average index'
.67±.09	.62±.10	.73±.08	.73±.08

The coefficients in Table I strengthen the case for the replacement hypothesis. They do not, however, give the final decision, because the probable errors are large.

For this reason, a further test of the hypothesis was resorted to. This involved comparison of 'corrected' and 'peak' indices in cases of certain specific relations between the phases of the cardiac response and of the breathing cycles. If the response-peak of one response comes at the peak of the breathing cycle, the response-peak of the other at the trough of the breathing cycle, the effect on the two measures should be quite different in the case of the two hypotheses suggested above.

If summation holds, the 'corrected index' (response-peak minus the value of the hypothetical cardiac breathing cycle at that point) should be the same whether the response-peak occurs at a peak of the breathing cycle or at a trough; the 'peak index' (response-peak minus average of peaks in last twelve seconds) should be greater when the response-peak corresponds to the peak of the breathing cycle. If replacement holds, on the other hand, the 'peak index' should be the same, the 'corrected index' greater for the trough.

The table below gives values for both indices for the subjects in whom the phase of the action peak corresponded in one experiment to the breathing cycle peak (column marked Peak), and in the other experiment to the breathing cycle trough (column marked Trough).

It can be seen that for the 'peak index' there is no consistent difference between the values measured from a peak and from a trough of the breathing cycle. The 'corrected index,' on the contrary, gives values consistently lower when the response peak occurred at a peak of the breathing cycle than when it occurred at a trough. Thus, both consequences of the replacement hypothesis hold, and neither consequence of the summation hypothesis.

TABLE II

Observer	'Peak index'		'Corrected index'	
	Peak	Trough	Peak	Trough
Le	9	2	12	16
Wh	7½	7	11	13
Gi	3	7	1	10
Wi	11	18	18	29
Totals	30½	34	42	68

Two conclusions may be drawn from this study of measures of cardiac startle, the one practical, the other theoretical.

The practical conclusion is that the best index of cardiac acceleration is the 'average index,' the difference between the highest peak of heart rate within the five seconds following stimulation, and the average heart rate during the twelve seconds preceding stimulation. The 'peak index' is apparently just as valid (cf. Table I), but takes longer to measure. Consequently, we propose that the 'average index' be called the *index of cardiac startle* and that this index be used in reporting individual differences in the startle response.

The theoretical conclusion refers to the neural mechanism of the cardiac startle response. The analysis of the results of the experiment, indicating as they do that the startle response is not a summative mechanism, suggests strongly that the startle response inhibits the breathing cycle mechanism under startle conditions.

There is a considerable body of physiological fact consonant with this view. Moore and Cannon (**6**) have shown that there is a constant tonicity of both the accelerator and depressor nerves of the heart. Inasmuch as sympathetic (accelerator) changes are slow, it can be assumed with moderate assurance that the cardiac variations associated with breathing changes are dependent on the activity of the depressor (parasympathetic,—vagus) nerves. Fredericq (**3**, 84), following Sanderson, adopted this interpretation, and Moore and Cannon (**6**) established it experimentally.

According to the possibility suggested above, that the startle response extinguishes the breathing cycle, the increment following the startle stimulus is due either to the relatively complete removal of depressor activity during the startle response (which would eliminate the cardiac arrythmia due to breathing, *and* raise the basal level); or it can be due to this factor plus the action of the sympathetic centers which are reciprocally related to the innervation of the parasympathetic nerves.

There are a number of reasons why the first of these possibilities is the better hypothesis:

1. The fact that the heart rate increment tends to approach a moderate ceiling (far below the values attained after exercise when the activity of the sympathetic system is apparent) suggests that the response is due to a mechanism which does not bring about an enormous increment in heart rate. The release of the depressor nerves is such a mechanism. Moore and Cannon (**6**) found an increase of 32 percent in the heart rate of cats on vagotomy, while in these same cats with the high basal rate induced by the lesion of the vagus, the heart rate increased about 75 percent with struggle. That is to say, the maximum effect of the release of the vagus is 32 percent, whereas the sympathetic nerves may induce an increment of 75 percent, perhaps more.

2. The increase is so rapid, and the return to the average level before the stimulus follows so quickly, that the sympathetic activity is unlikely. Beebe-Center and Stevens (1) have indicated that in cats the response to shots is too rapid to be due to accelerator nerves.

3. In Figure 5 there is a noticeable negative phase following the action peak. The variations in the response after the first few seconds would be expected to center around −30 (as indicated on the ordinate), but for a second or two the heart rate values more nearly average −40 or −45.

Rosenblueth and Simeone, in working with cats, sectioned both the sympathetic and parasympathetic nerves leading to the heart. The two sources of innervation could then be stimulated separately. "The slowing induced by the vagus alone is succeeded by a moderate acceleration, due probably to some accelerator fibers contained in the nerve" (**8**, 45).

This is the same condition as would exist if the startle response reduced the vagus effect to a minimum and then on recovery permitted the vagus to begin functioning again. The few accelerator fibers present, in taking longer to act, would not make their influence felt for a few moments, thus allowing a slight negative phase.

The Nature of Cardiac Startle.—Although the experiments described above were determined largely by the desire to discover a relatively stable index of cardiac startle, they were so devised as to yield in addition certain information, in terms of this index, concerning the characteristics of the cardiac startle response.

A. Magnitudes and Action Times of Individual Responses.—Figure 6 indicates the distribution of magnitudes of response, in terms of the index of cardiac startle (difference between peak rate in five seconds after stimulus and average for twelve seconds before stimulus), for the first shots heard by the twenty-seven subjects used in the present experiment. The outstanding feature of this distribution is its range, auguring well for the use of this index in connection

with individual differences. Figure 6 also gives the distribution of action times (time from stimulus to highest peak in five seconds after stimulus). The mean is 3.02 seconds. The majority of cases are clustered rather closely about this value which indicates that the response is fairly constant.

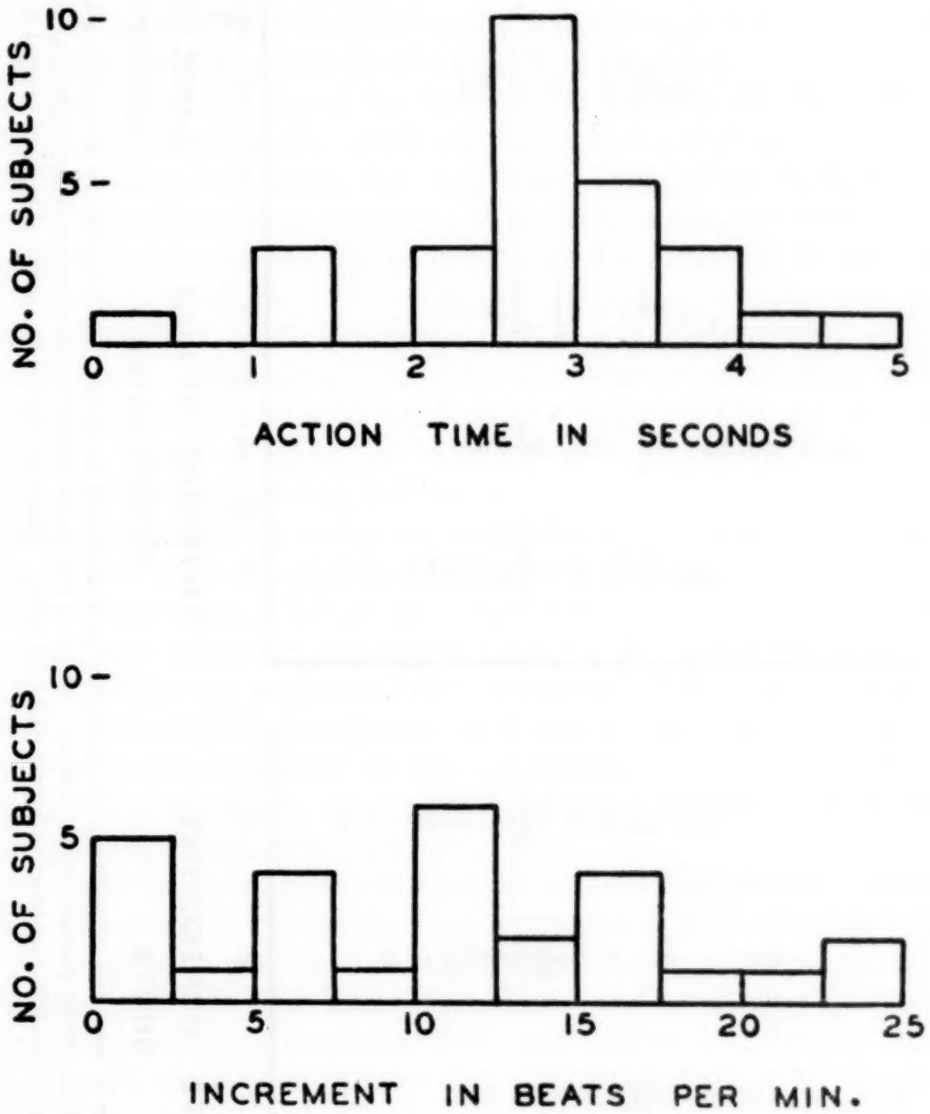

FIG. 6. Magnitudes and action times of individual responses of 27 subjects to first shot of experiment. Responses measured in terms of the index of cardiac startle [*i.e.*, difference between fastest rate in 5 seconds following stimulus and average rate for 12 seconds before stimulus].

B. Habituation.—Inasmuch as a series of shots had been used with most of the subjects, any habituation effect, if present, could easily be studied. With twenty-one of the twenty-seven subjects there were three shots in succession at the beginning of the record on the first day of stimulation. With six of these subjects there were also three shots in succession on the second day of stimulation. The

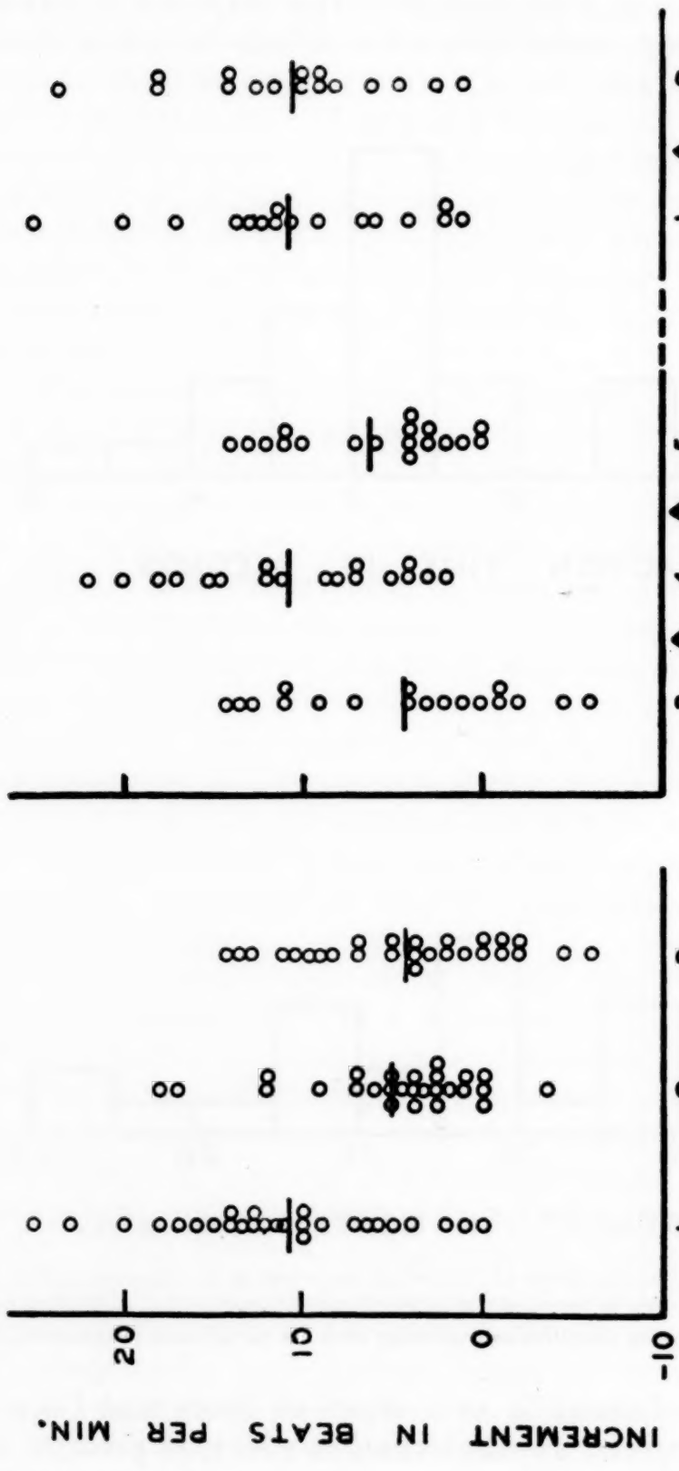

FIG. 7. Effect of repeated stimulation on increase in heart-rate due to shots. Circles indicate individual data in terms of the index of cardiac startle, bars indicate averages. Chart at left shows effect of 3 consecutive shots. Chart at centre shows effect of interpolated stimuli on responses to fourth and fifth shots. Chart at right shows effect of lapse of several days between shots.

data from these twenty-seven sets of three successive shots are plotted in Fig. 7 at the left. It is apparent in the shift, both of ranges and of averages, that the response to the startle stimulus undergoes a diminution if one stimulus follows another within the space of a few minutes.

The usual procedure (in eighteen of the twenty-seven cases) after the first three shots was to insert a different stimulus (either a brushing of strings over the face or the sound of an imitation 'moo'). As can be seen from the graph in the central portion of Fig. 7, such a stimulus inserted after the third shot acted as a distraction stimulus or dehabituating influence, for the fourth shot was as effective as the first. Apparently it made no difference what the stimulus was that was interpolated as long as it provided a suitable 'break' in the experimental procedure.

Sixteen subjects returned for a second experiment after a period of several days. The comparison for the first shots of these subjects on the two occasions is indicated at the right of Fig. 7. It can be seen that a lapse of days, as well as an interpolated stimulus, is effective as a dehabituating influence.

These results bear a remarkable similarity to those of Prosser and Hunter (7) in work on the experimental extinction of the startle response in white rats. These investigators found that the repetition of an auditory stimulus for approximately 65 times resulted in the extinction of the leg response (their measure of the startle response), but that a disinhibiting stimulus, such as the flashing of a bright light in front of a rat, resulted in the reappearance of the startle (leg) response. Furthermore, an interval of fifteen to twenty minutes was sufficient for spontaneous recovery.

Although the present investigation had no adequate technique to indicate the time involved in total extinction and spontaneous recovery, the general picture is entirely consistent with that established by Prosser and Hunter for rats. The cardiac startle response in human beings undergoes extinction, and either a different stimulus or a lapse of time is sufficient for the disinhibition of the startle response.

C. Relation to Movement.—Because skeletal movements and breathing variations are associated with cardiac disturbances, measures were used to indicate the change in these functions concomitant with the startle response. Table III treats for five successive shots the three types of measures used. The number of cases was 18.

The middle section of the table deals with the irregularity in the breathing record, which follows the stimulus very immediately and which resembles a tooth (*cf.* Figs. 2*a* and 2*b*). This pattern may be due to a quick inspiration followed by as rapid an expiration, or it

TABLE III

Shots		1	2	3	4	5
Change in rate of breathing	Number accelerated	12	10	6	10	7
	Average acceleration	1.02	.99	.94	.99	.97
Amplitude in mm of 'tooth'	Number with response	18	11	9	10	11
	Avg. absolute resp.	4.5	2.1	2.4	2.3	1.7
	Abs. amplitude / Amp. last br. cycle	1.20	.54	.74	.81	.61
Average duration of action current in seconds		.21	.11	.13	.12	.09

may be due to an abrupt skeletal movement of the thoracic region of the trunk. The pneumograph record does not permit the differentiation of these two types of movement.

It can be seen from the table that this measure also exhibits an habituation function similar to the cardiac change in Fig. 7. There is, however, a general irregularity in the response for the third shot. Furthermore, as with all the measures of movement, there was an enormous scatter when cardiac acceleration (in terms of the 'average index') was plotted against magnitude of overt response for individual responses.

As another measure of skeletal movement, duration of action currents on the cardiograph was used. Inasmuch as the cardiograph operates with the voltage difference induced by muscular contraction, any movement occurring with the startle response is indicated on the record as well as the contraction of the cardiac muscle. As for the 'tooth' of the breathing record, the third shot occasions a response that conforms roughly with the cardiac habituation function, but not in detail.

The first measure of skeletal movement indicated in Table III is the acceleration of the breathing following the stimulus. The changes can be seen to follow exactly the cardiac habituation pattern. The differences are small, however. It may be concluded that although the various measures of movement used here tend to demonstrate a relation to cardiac changes because of similarity to the average cardiac responses, the techniques involved lack the adequacy to make a convincing statement of the relation. The problem remains for further experimentation.

D. Reported Startle.—At the end of each experiment the subjects were asked to evaluate the strength of the startle after each stimulus. In twelve of the eighteen cases dealt with in Table III the first response was reported to be stronger than both the third and fifth.

Here we find evidence of habituation, but not of any detailed relation to the habituation of the cardiac response. Again, it appears that the technique is at fault. The chief difficulty with these introspective reports lay in the fact that they were secured at the end of the experiment, and it was necessary to rely on the subject's memory. To achieve any reliable success with such introspective reports it will be necessary to use a scale of evaluation and immediate report after each shot.

E. Individual Differences.—It will be remembered that one of the criteria used in the first part of this paper to decide between various indices of cardiac startle was the self-correlation of these various indices when stimulation occurred in opposite phases of the breathing cycle. For the index finally recommended as the index of cardiac startle (the 'average index'), this correlation was not only high relative to the values of other indices, but high in absolute terms. It was .73 ± .08 for sixteen observers. This fact suggested that this index might prove useful as a measure of individual differences in autonomic emotional sensitivity. To test this possibility further, seventeen additional observers were subjected to a single shot on two occasions separated by one to three weeks. The shots occurred in opposite breathing phases.

The coefficient [obtained by the Garrett (4, 275) raw-score formula] for the combined data is .53 ± .08. The coefficient yielded by these additional data by themselves was .32 ± .15. These figures show either that the index of cardiac startle is not nearly as reliable as was suggested by the earlier high coefficient, or that control was badly inadequate in the later experiment. Figure 8 shows the individual values of the index from which the two coefficients were computed. Circles represent the earlier experiment; dots the later. It will be noted that for both experiments the data constitute a definite band, except for three discordant cases, two of which belong to the later data. This suggests that the low reliability shown by the later data may well be due to lack of proper control of a few isolated cases.

This suggestion is supported by the facts in the case of the most inconsistent individual (upper left dot). The subject in this case had a basal level in the first session of 72 beats per minute, in the second session a level of 104 beats per minute. Sufficient time was not allowed in the second session for him to 'quiet down' after the comparatively strenuous exercise of hurrying to the laboratory in the third floor of Emerson Hall. The attitude in the second experiment was probably quite different from that in the first experiment, inasmuch as the subject was worried whether or not he would arrive at a laboratory meeting in time. Without this individual the coefficient for the total data is .66 ± .08.

Explaining away discordant cases is certainly no proof of reliability. Such proof can only come from further data. Our discussion does suggest, however, that, with proper control, reliability represented by a coefficient well above .50 should be attainable. We plan

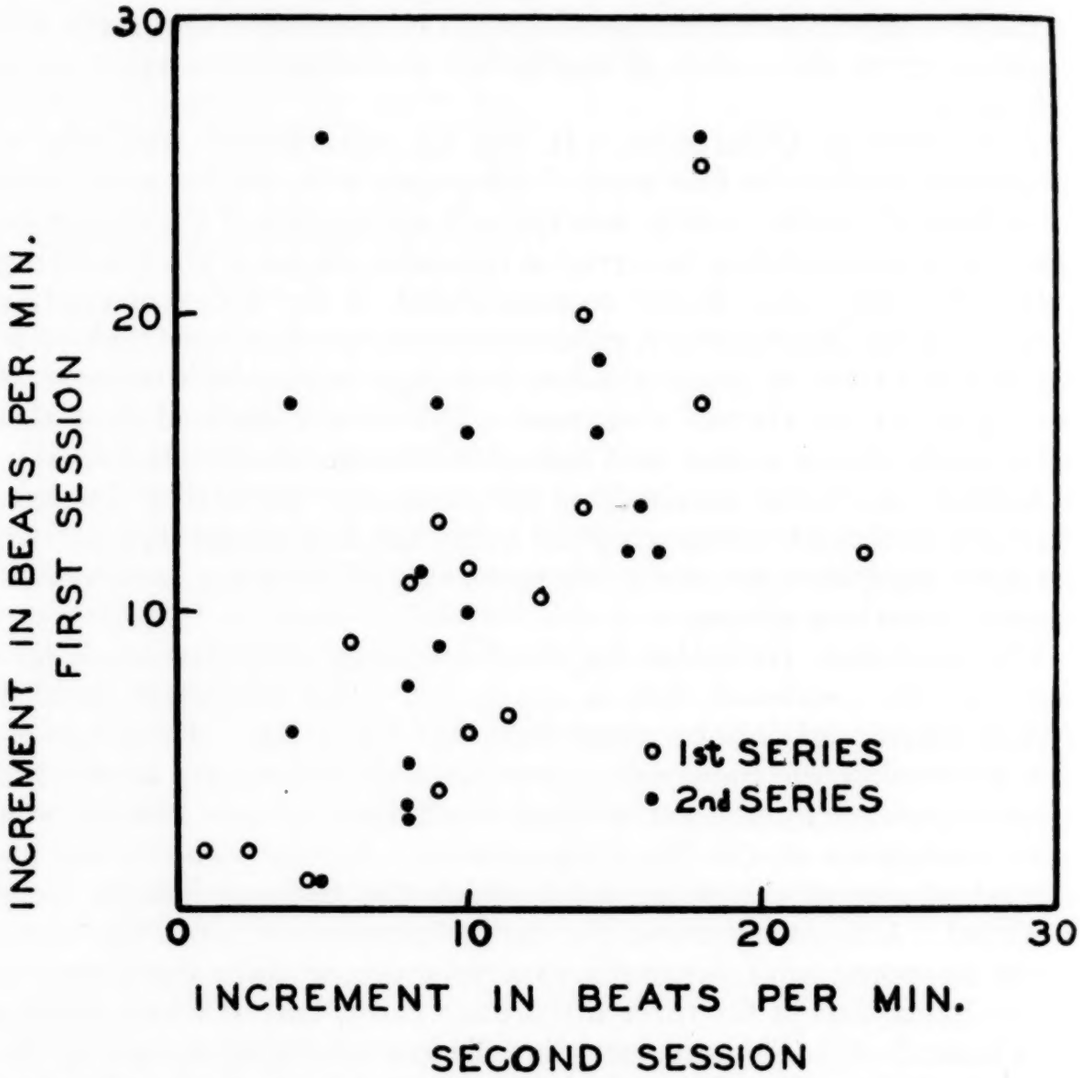

FIG. 8. Relation between cardiac startle responses of individuals on two different occasions. Responses measured in terms of the index of cardiac startle.

to pursue this question with particular emphasis on uniformity of preliminary period both with respect to time and to attitude.

Summary.—1. The increment in heart-rate due to startle stimuli is best specified in terms of what we may call the index of cardiac startle, namely, the difference between the peak rate in the five seconds following the stimulus and the average rate for the twelve seconds preceding the stimulus.

2. From the nature of the index of cardiac startle it seems likely that the neural mechanism responsible for the increment in heart-

rate is the release of vagal inhibition of the heart and not an increase in sympathetic activity.

3. The startle response becomes habituated by successive shots, but the response may be disinhibited by the interpolation of either a different stimulus or a lapse of time.

4. There is some indication that the increment in heart-rate is positively correlated with subjective report of startle and with skeletal movement.

5. The repeat-reliability of the index of cardiac startle on thirty-three subjects was .53 ± .08. It is likely that with certain specified controls this reliability may be considerably increased.

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EXPERIMENTS ON MOTOR CONFLICT. II. DETERMINATION OF MODE OF RESOLUTION BY COMPARATIVE STRENGTHS OF CONFLICTING RESPONSES

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In a previous study (3), it was shown that the mode of resolution of a motor conflict is determined to some degree by the kinds of responses (whether approach or avoidance) which are in conflict. The proportion of instances in which 'blocking' occurred, for example, was five times as great when the conflict was between two avoidance responses (Type III conflict) as when it was between two approach responses (Type I).

On theoretical grounds it would be expected that another factor influencing the mode of resolution would be the *relative strengths* of the conflicting responses. With considerable disparity in strength the stronger response might easily override the weaker, while with equal strengths frequent blocking would be predicted. The hypothesis is advanced that *frequency of blockage increases as the strengths of the conflicting responses approach equality.*

The chief experimental problem involved in testing this hypothesis is the measurement of the relative strengths of the conflicting responses. In the first of the two experiments described below it was assumed that avoidance reactions established with the aid of electric shock punishment were stronger than ones established by instructions alone. In the second, the relative strengths were assumed to vary positively with the amount of practice of the reactions. In other words, intensity of punishment and amount of practice have been used as the coordinating definitions for strength of response. In both experiments the conflicts were between incompatible avoidance responses (Type III conflicts).

I

METHOD

Apparatus.—The incompatible manual responses between which conflicts were induced can best be described in relation to the apparatus. The subject was seated on a high stool directly in front of the box-like apparatus. From the top of the box protruded a lever, inserted in a universal joint; inside the box the lower end of the lever, with an appropriate spring extension, rested on a composition plaque containing five plate-brass insets. The handle of the lever could be moved in any direction, therefore, and the lower end, pressing against the brass plates, moved in the opposite direction. The total possible excursion of the lever handle was three inches in any direction from the vertical position. The lever and these brass plates were wired in such a way that the subject received the electric shock through the lever handle which he grasped. The

positions of the lever in which shocks would be received could be varied as the experimental conditions required.

The apparatus described by Muenzinger and Walz (5) was used as a source for the shock. This circuit provides a relatively constant amount of current despite changes in body resistance. The strength of shock was varied from subject to subject, the amount used being determined by preliminary tests. The subject was asked to judge when the shock became "definitely painful" and this amount was then employed throughout the session.

Flashes of uncolored flashlight bulbs, mounted on each side of the top surface of the box, were used as signals for the subjects to make the instructed responses.

Instructions and Procedure.—The subjects, undergraduate men paid for their services, were divided into three groups of fifty each.

Group A.—The subject was instructed to grasp the handle of the lever firmly and when either light flashed on to move the lever away from the light as quickly as possible. Nothing was said about shock and no shocks were given on any trial. After ten reactions away from each light, in random order, both lights were flashed simultaneously for the 21st trial.

Group B.—After preliminary tests to determine the proper intensity of shock, the subject was instructed as above, except that he was told he would feel a shock when one of the lights flashed on and that moving the lever in accordance with the instructions would stop the shock. For half the subjects (Group B1) the shock was associated with the *left* light, and for the other half with the *right* light (Group B2). The subject was told in advance with which light the shock would be associated. After ten trials to each light, in random order, both lights were flashed simultaneously for the 21st trial. No shock was given on this conflict trial.

Group C.—The instructions and procedure for this group were the same as above, except that the subject was told there would be shock accompanying *each* light. No shock was given on the final conflict trial.

The light and shock stimuli were presented simultaneously by a manually operated double-pole switch. The light stimulus on the practice trials was of approximately one second's duration, and on the conflict trials remained on until the subject either made some response or definitely indicated that he was not going to respond, *e.g.*, by removing his hand from the apparatus or by asking a question. When shock stimuli were presented, the circuit was broken as soon as the subject moved the lever more than an inch away from the light. If he made the error of moving *toward* the light, the shock continued.

Results

The influence of different relative strengths of conflicting responses on the modes of resolution of the conflicts can best be described in terms of the four classes of response described in the first paper of this series (3). These four modes of resolution are as follows:

1. *S*—*single* reaction only; *i.e.*, moving the lever directly away from one light and toward the other.
2. *D*—*double* reaction; *i.e.*, going first to one side and then to the other.
3. *C*—*compromise* movements. These are of greater variety with the present apparatus than with the V-shaped conflict board used in the earlier study, possibly because the lever in its universal joint permits movement in a field of 360° rather than of only 180°. Some of the *C* resolutions were a circular spinning of the lever and others involved movements toward apparently irrelevant parts of the field.[1]
4. *B*—*blocking*; either no manual response whatever, or one so slight that, with the present apparatus, the lever failed to move more than one inch from its original central position.

[1] Factors determining the nature and frequency of these compromise resolutions are described in a forthcoming paper (4).

In Table 1 are given the proportions of subjects in each group who resolved the conflict by each of the four modes. As is predicted by the hypothesis, the number of blockages for Group B (unequal strengths) is far less than the number for either A or C (equal strengths). A chi-square analysis of the results was made by dividing the responses of each group into two categories, blocking and non-blocking. The results indicated that the differences between A and B, and between B and C, would arise by chance less than once in a hundred times.

TABLE 1

THE PROPORTION AND S.D. OF THE PROPORTION OF CASES IN EACH GROUP RESPONDING WITH EACH OF FOUR MODES OF RESOLUTION

Group	Description	N	Mode of Resolution							
			S		D		C		B	
			%	S.D.%	%	S.D.%	%	S.D.%	%	S.D.%
A	No shock on either side	50	28	6.3	6	3.4	2	2.0	64	6.8
B	Shock on only one side	50	46	7.0	12	4.6	14	4.9	28	6.3
C	Shock on both sides	50	40	6.9	2	2.0	2	2.0	56	7.0

The validity of these data as a demonstration of the hypothesis set forth above rests on the assumption that the two responses, in Group B, were actually of unequal strength. There is internal evidence that this was the case. It would be expected that the response reinforced by shock would occur more frequently than the other, when either one occurred at all. An overt reaction involving an immediate movement toward one side or the other was made by thirty-eight of the subjects in Group B; this figure is obtained by including (*a*) all Single responses, (*b*) the direction of first movement of all Double responses, and (*c*) the direction of abortive movement in all instances of Bloackage in which there was a detectable involuntary start. Of these thirty-eight responses, 25 were shock-avoidant, and 13 were shock-approach. This amount of deviation from an expectancy of equility would occur by chance only once in fifty times. In both Group A and C, however, where both lights had the same stimulus value, a laterality factor was apparent, 64 percent and 69 percent of the responses involving movement to the left. Since half the subjects in Group B were trained *in opposition* to this tendency, the real difference between frequency of shock-avoidant and shock-approach reactions would be even greater than that indicated by the above statement of probability.

The initial assumption that association of shock punishment with one avoidance response would give it greater strength than its opposing non-shocked competitor appears to have been validated, therefore; and further, the original hypothesis that the more nearly equal in strength the conflicting responses are, the greater the probability of blockage, has been affirmed.

II

Method

Apparatus.—The apparatus used in this second experiment has been diagrammed and described in detail elsewhere (3). Briefly, the subject was seated before a table on which rested a 6″×6″ metal plaque. The edges were made of 1″ brass stripping and in the middle of the side toward the subject this stripping contained a small nick on the inner edge. The subject rested a pencil in this nick. An uncolored flashlight bulb was mounted at each of the upper corners of the board. The flashes were controlled by an operator seated behind a large screen which hid the switches from the subject.

Instructions and Procedure.—The subjects were divided into four equal groups. Each group was given a different amount of practice on the two incompatible responses of avoiding whichever of the lights flashed on. This constituted preparation for a Type III conflict.

Group D.—The subject was instructed to rest the point of his pencil on the wax paper in the nick and respond as quickly as possible to the flash of a light by drawing a line *away* from that light to the opposite upper corner. He was given only one practice trial to one of the lights, but twenty trials to the other; the single trial was given as the second of the series of trials. For half the subjects the single trial was to the right light, and for the other half, to the left. Both lights were presented simultaneously for the 22nd trial.

Group E.—Same instructions, but five practice trials were given on one side, and twenty on the other. The sides were balanced as with Group D above. Both lights were presented on the 26th trial.

Group F.—Same instructions, but each light was presented twenty times in random order for the practice trials. Both lights were presented simultaneously for the 41st trial.

Group G.—Same instructions, but five practice trials were given on each side. The conflict was produced on the 11th trial.

Subjects.—The one hundred sixty subjects were boys attending a Y.M.C.A. summer camp. They varied in age from 10 to 15 years, but the four groups were equated with respect to age. The subjects served voluntarily.[2]

Results

The amount of practice provided for each of the four groups varied in such a way that Groups D, E and F provide an ascending hierarchy in the size of the ratio between the amounts of practice on the two conflicting responses. Group G has the same *ratio* as F, but with a smaller absolute amount of practice.

Comparison of the frequency of blockage (resolution 'B') in Table 2 indicates that, with the approach of the ratio to unity, there is an unreliable increase in difficulty of resolving the conflict. Chi-square analyses indicate that the differences between D and E and between D and F just fail to reach the 1 percent level of significance. There

[2] The writers are greatly appreciative of the kindness of the Connecticut State Y.M.C.A. in making this study possible, and are indebted to Dr. Glen L. Heathers for assistance in obtaining the data.

is little difference between E and F, but the difference is in the expected direction.

TABLE 2

THE PROPORTION AND S.D. OF THE PROPORTION OF CASES RESPONDING WITH EACH OF FOUR MODES OF RESOLUTION FOLLOWING FOUR DIFFERENT AMOUNTS OF PRACTICE

Group	Relative Number of Practice Trials	N	Mode of Resolution							
			S		D		C		B	
			%	S.D.%	%	S.D.%	%	S.D.%	%	S.D.%
D	1 : 20	40	17.5	7.7	30.0	7.2	20.0	6.3	32.5	7.4
E	5 : 20	40	15.0	5.6	17.5	6.0	15.0	5.6	52.5	7.9
F	20 : 20	40	2.5	2.5	22.5	6.6	17.5	6.0	57.5	7.8
G	5 : 5	40	5.0	3.5	15.0	5.6	30.0	7.2	50.0	7.9

DISCUSSION

In the preceding section, our results have been interpreted as confirming the hypothesis that frequency of blockage is maximal when the strengths of competing responses are equal. An alternative interpretation is possible, however, if one starts with the definition of *strength of response* as the ability to compete successfully with simultaneously instigated incompatible responses (1, p. 4). The present experiments, then, might be interpreted as verifying the assumption that both adding shock punishment and increasing the amount of practice serve to strengthen avoidance responses. That is, the frequency of blockage would be used in the operational measurement of strength of response. The choice of these interpretations depends largely on the systematic setting in which the elucidated factors are to be used. Since shock punishment and practice are ordinarily used as operational definitions of response strengtheners, we have used the data as supporting the first hypothesis, viz., that blockage varies positively with the approach of the conflicting responses to equality in strength.[3]

From a therapeutic standpoint the principle studied in this experiment may have considerable significance. In situational conflicts (in which the instigators to the two responses are external to the organism and are perceived as clearly separate), the increase of strength of instigation to one response, while the strength of instigation to the other is held constant or lessened, would assist in overcoming indecision and permitting a compromise or direct single

[3] Still a third statement of the relationship is possible—that the data demonstrate a positive correlation between two operational definitions of strength of response.

resolution of the conflict. There is nothing novel about this principle; it is the basis of all disciplinary technique in which threat of punishment is used to overcome the disciplinee's initial reluctance to carry out some act which the disciplining authority requires. Increasing the threat of punishment can operate in this manner, however, only if the opposing response is one which the organism has the ability to make, or is not so strongly instigated that no socially possible punishment can provide a greater competitive strength. The muteness of witnesses under third degree treatment may represent a blockage of verbal responses consequent upon this latter condition.

A distinction must be made here between *situational* conflicts of Type II (approach-avoidance) and III (avoidance-avoidance) character, on the one hand, and *internalized* Type II conflicts. Little is known, except clinically, of the influence of strengthening the basic drive-instigation when this latter is the instigator for both positive and negative (anxiety) actions. Clinical evidence is abundant, however, to show that such strengthening increases both anxiety and inhibition of action, presumably with a consequent increase in generalization of inhibition to action systems other than the one immediately subject to the Type II conflict.

The present data throw little light on the influence of the *absolute* strength of the conflicting responses. In the shock experiment, Group A (no shock) had slightly more Block reactions than Group C (both sides shocked). In the second experiment, however, Group G (five trials practice on each side) had slightly fewer than Group F (twenty trials to each side). Neither difference is of statistical significance and it may be that the absolute difference in strengths of the responses produced by these two conditions was insufficient to show any effect that such a factor may have. On theoretical grounds, as well as from indirect evidence from other experiments (**2**, **6**, **7**), it would be expected that with the ratio of strengths held constant, the amount of blockage would vary positively with absolute strengths of the conflicting responses.

Summary

In two experiments with Type III (avoidance-avoidance) motor conflicts, the relative strengths of the conflicting responses have been systematically varied. In one, the variation was produced by combining shock punishment with instructions, and in the other, by varying the amount of practice of the responses. Both sets of results indicate clearly that *the probability of blockage as a reaction to conflict increases with the approach of the strengths of the conflicting responses to equality.*

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